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Dyslexia, Auditory Laterality,

and Hemisphere-Specific Auditory Stimulation

Researchers from several disciplines (education, psychology, speech and language) agree that half of the population with specific reading difficulties have inherited the problem. But what may be the cause of the problem in the other half of the population?

We now know that the majority of people suffering from specific reading difficulties (dyslexia) - with or without occurrence of the problem in the family – have had or still have specific phonological/phonemic difficulties with language perception and production.

According to parents' answers to a questionnaire from our lab during the academic year 2001, 26% of the children came from families with reading problems, 22% of the children had suffered recurrent middle ear infections early on, 36% had suffered recurrent middle ear infections early on <u>and</u> came from families with reading problems, 16% had no such problems registered (N=50, mean age 10;6, mean reading age < 8;6).

One line to persue, therefore, in dyslexia research, could be that of insufficient auditory sensation and perception (either inborn or acquired) in early childhood.

Several definitions of dyslexia explicitly state that this learning disability is not related to sensory problems. Our work questions that statement. One problem might be that assessments of sensory problems too often are insufficient.

(The 2003 definition from IDA does not state this (Lyon, Shaywitz & Shaywitz, 2003), while the IDA definition from 1994 did as also the 1981 definition from the National Joint Committee for Learning Disabilities)

Research has shown that there are individuals who, despite apparent normal peripheral hearing sensitivity, exhibit central auditory processing disorders (CAPD or just APD) that may be related to language problems, including problems in reading and spelling (developmental dyslexia).

At the same time in most dyslexia research, assessments, and intervention programs it is implicitly assumed that both the peripheral and the central sensory processings are well functioning. This may not be the case.

It has been found in an animal model that auditory discrimination abilities may progressively improve with practice (Merzenich et al., 1993).
It has been suggested that similar improvements may be induced in children using special auditory stimulation techniques (Stein, 2001).

The results reported in the following paper seem to indicate that simple assessment techniques, such as precise determination of hearing thresholds for different frequencies, together with binaural audiometry and dichotic listening to decide discrimination abilities and auditory laterality, may contribute to the diagnosis of what is generally considered to be a central processing problem often out of reach by normally applied teaching methods.

Furthermore it is indicated that specific and individualized auditory stimulation programs which are based on such assessments and where the perception of AM (amplitude modulation), FM (frequency modulation), and TM (temporal modulation) of auditory input is trained by listening to individually formatted music tapes or CDs may improve the perception of CV syllables and thus positively support remedial education by improving auditory discrimination abilities.

Keywords: auditory laterality; auditory processing; auditory stimulation; dyslexia.

INTRODUCTION

The recent debate related to the work published by P. Tallal and M. Merzenich (Hook, Macaruso and Jones, 2001; Macaruso and Hook, 2001; Bellis, 2002, pg. 270) may make it appropriate to add similar ideas involving non-verbal auditory stimulation to the discussion.

Since 1987 the Sensomotoric Centre in Mjölby, Sweden has successfully used reflex- and visual stimulation programs and since 1990 has also used hemisphere specific auditory stimulation (ADT/HSAS/IAS/JST) programs with a total of some eight hundred students with learning problems (Sohlman, 2000, pg. 16). The auditory stimulation is based on assessment procedures comprising hearing tests (audiometric testing of hearing thresholds and auditory laterality plus some form of dichotic listening). The students are assessed prior to and post intervention.
In the light of published results from this training and of recent research referred below, it was decided to carry out a retrospective study of students who had attended this center.

Quotations

"Animal research has suggested that auditory deprivation induced by lack of environmental stimulation or by conductive hearing loss results in incomplete maturation of most auditory neurons in the brainstem: "There is a critical period for development of brainstem nuclei.... Without adequate sound stimulation during this period, most brainstem auditory neurons do not fully develop" (Webster & Webster 1979, p. 687). In light of Brainstem Auditory Evoked Response research that indicated that brainstem maturation in the human may continue into the third year of life (Kaga & Tanaka 1980), auditory deprivation during this period, regardless of the cause, may have devastating consequences for the development of normal auditory processing. This finding is consistent with studies of the effects of chronic otitis media, indicating that early hearing deficits adversely affect later central auditory functioning, and supports the sensitive period hypothesis of language acquisition.” (From Spreen *et al.*, 1995, pg. 418).

”A carefully controlled prospective study of 207 children from birth to 7 years found a significant association between time spent with middle ear effusion during the first 3 years of life and both Verbal and Performance IQ scores and scores in mathematics and reading, as well as articulation and the use of phonological markers, Length of time with otitis media after age 3 was not related to outcome at age 7.” (From Spreen *et al.*, 1995, pg. 433).

”However, it is known that severe otitis media during early childhood can lead to language problems and then to dyslexia (Merzenich and Jenkins, 1995).” (From Livingstone, 1999, pg.89).

“From cognitive and educational psychology we have learned that children must be trained to hear the individual sounds (phonemes) of their language. They must be able to disconnect or ‘unglue’ sounds in words in order to use an alphabetic writing system.” (McGuinness, 1997).

“If we take the stand that each individual is a unique case, then the health issue does not lend itself to statistically significant double blind tests involving hundreds of identical cases and control groups. Simply because reality does not conform to the statistical rules of science. Simply because each and every human being, each and every human illness, and each and every human destiny is unique and unreproduceable.” (Jerndal, 1999).

“Until recently, many thought developmental dyslexia was a behavioral disorder that primarily affected reading. In fact, it is a partly heritable condition, the clinical manifestations of which are extremely complex including deficits in reading, working memory, sensorimotor coordination, and early sensory processing. Even though extensive research has characterized these behavioral abnormalities carefully, the biological mechanisms of the clinical manifestations are still poorly understood.” (Zeffiro and Eden, 2000, pg. 3).

“For example, research on remediation of developmental reading disorders has been hampered by reliance on the coarse, pretheoretical category of developmental dyslexia. Whereas this category is almost certainly heterogeneous, most developmental dyslexia research implicitly assumes that the underlying cognitive dysfunction is the same in all (or at least most) dyslexics. As a consequence, most remediation studies have examined undifferentiated groups of dyslexic individuals, and have been aimed at formulating a single set of methods for across-the-board application. Among the results of this approach are disappointing success rates, and widespread failure to replicate.” (McCloskey, 2001, pg. 607).

“It stands to reason that selective, subtle sensory and motor problems *may* interfere with dyslexics’ reading and writing.” (Berninger, 2001, pg. 37).

”Ideally, however, we would like to clinch the causal argument that poor AM and FM sensitivity prevents the acquisition of good phonological skill by showing that improving children’s AM and FM sensitivity by sensory training will help them to acquire phonological skill”. (Stein, 2001, pg. 14).

“I believe that, if we continue to look for a simple answer to Auditory Processing Disorder (APD), it will continue to elude us. As long as we try to agree on easy, concise definitions, methods of diagnosis, and methods of treatment for APD, we will never reach consensus on anything. The brain is infinitely complex. Any disorder that involves the brain will, likewise, be infinitely complex. Therefore, until we let go of the hope for a simple answer, we may find ourselves never asking the right questions.” (Bellis, 2002, pg. 318; See also Bellis, 2003).

“Duration measurements and a rating system based on first and second formant values were used to analyze production performance. As a group, the students with reading disabilities not only perceive but also produce less well-defined vowel categories than the control group of age-matched good readers. Perception and production performance, however, were not correlated.” (Bertucci *et al.*, 2003).

”This study (by Overy) is particulary interesting in that it shows specific effects on some, but not all, aspects of language performanc in dyslexic children. This is a clear demonstration that music’s effects are not the result of some general overall “motivation” or “priming” effect, but are a consequence of specific overlaps between cognitive components af music processing and related components of nonmusical tasks.” (Sloboda, 2003, pg. 390).

”The observed differencies in the development of these basic neurally based perceptual abilities may underlie the faulty processing of speech-related information postulated by other researchers as underlying the development of reading skills.” (Espy *et. al.*, 2004, pg. 33).

”These findings suggest that perceptual mechanisms to the full sound spectrum, both speech and nonspeech sounds, are important in later reading ability.” (Espy *et. al*., 2004, pg. 34).

”In the domain of phonetics and phonology we have seen that the catego-rical perception of stop consonants in at-risk children around age 4 is signifi-cantly less clear-cut than in the control group, and in fact not distinguisably better than in children with SLI. This is suggestive of a spech recognition problem.” (van Alphen *et al.*, 2004).

”It can be concluded that work needs to be done on improving processing in the phonological channel (accuracy and speed) for all dyslexics in order to help them attain faster speed of processing in this channel, and as a result their reading may also be improved.” (Miller-Shaul, 2005).

“In sum, we found more robust and faithful encoding of linguistic pitch information by musicians. Such encoding, arguably associated with increased musical pitch usage, may reflect a positive side effect of context-general corticofugal tuning of the afferent system, implying that long-term music-making may shape basic sensory circuity. These results complement our existing knowledge of the brainstem’s role in encoding speech and frequency modulation by demonstrating the interplay between music and speech, subcortical and cortical structures, and the impact of long-term auditory experience.” (Wong *et al.*, 2007, pg. 2).

Recent research

Wiesel and Hubel (1963) investigated the effects of early sensory deprivation on newborn animals. They found that visual deprivation in one eye profoundly alters the organization of ocular dominance columns. Columns in the occipital lobe receiving inputs from the closed eye shrink, and those receiving inputs from the open eye expand.

Our suggestion is that similar effects on the auditory cortices may result from deprivation in the auditory domain during sensitive periods early in life.

Evidence exists that weakness in the auditory identification of speech sounds is one of the causal factors in poor reading skills (Clark & Richards, 1966; Goetzinger, 1962).

Leviton and Bellinger (1986) concluded on the basis of a meta analysis of several studies that there is a convincing association between early and persistent otitis media and later reduction in language function as measured by paraphrase quality.

Bess, Tharpe, and Gibler (1986) reported that children with unilateral, *right ear impairment* tended to have poorer syllable recognition scores than left ear impaired children, but found no apparent explanation for this difference.

Auditory system plasticity may result in deprived speech perception if hearing, especially in the right ear, has been reduced during some critical periods of early life (Jensen, Børre, and Johansen, 1989). Their results confirmed that *right ear impaired* children perform significantly poorer than their left ear impaired counterparts especially in verbal subtests that are sensitive to minor input/processing damages.

Brain imaging studies and postmortem examinations of individuals with dyslexia, learning disabilities, ADHD, and normal controls have revealed functional, morphologic and structural differences in the auditory areas of the brain that are activated when listening to simple tonal complexes, language and music (Galaburda and Kemper; 1978; Hynd *et al.*, 1990, 1991).

Recanzone *et al.* (1993) trained owl monkeys for 60-80 daily sessions to make fine-pitch discriminations in selected regions of the auditory frequency spectrum. Tonotopic mapping carried out invasively afterward showed that the cortical area tuned to the trained frequency spectrum was enlarged by a factor of 2 to 3 compared to untrained monkeys.

We propose that similar effects may be obtained in the primary auditory cortex after hemisphere and frequency specific auditory stimulation (HSAS).

Other researchers have concluded that some children's discrimination deficits originate in the auditory pathway before conscious perception and have implications for differential diagnosis and targeted therapeutic strategies for children with learning disabilities and attention disorders (Korpilahti, 1996; Kraus *et al.*, 1996).

Wright *et al.* (1997) reported that children with specific language impairment have auditory perceptual difficulties in certain temporal and spectral sound contexts and are less able than controls to take advantage of a frequency separation between a tone and noise to aid detection of a tone. They concluded that the temporal and spectral specificity of the auditory perceptual deficits reported may serve to guide the search for the underlying neural bases of language disorders.

Näslund, Johansen and Thoma (1997) reported from a study with 59 Danish subjects that dichotic listening (DL) predicts reading performance, but language laterality variations among handedness and gender groups must however be considered.

There is some evidence that early asymmetry is linked with later language abilities. Infants who show early left hemisphere processing of phonological stimuli show better language abilities several years later (Mills *et al*., 1997)

Shtyrov *et al*. (1998) found that during background noise, the hemispheric balance of the processing of speech sounds shifts from its left-hemispheric dominance toward the right hemisphere.

Plasticity is now recognized as a fundamental property also of the central neural system (Diamond, 1988; Buonomano and Merzenich, 1998).

It has been widely believed that the sensory cortex matures early in life and thereafter has a fixed organization and connectivity. We now know that the cortex can be reshaped by experience. In one experiment, monkeys learned to discriminate between two vibrating stimuli applied to one finger. After several thousand trials, the cortical representation of the trained finger became more than twice as large as the corresponding areas for other fingers (Buonomano and Merzenich, 1998).

Helland and Asbjørnsen (2001) found that dyslexic subgroups showed a deviant asymmetry pattern compared to a control group with a weaker response pattern to right ear stimuli than controls.

Pantev *et al.* (2001) documented in a study of ”functional deafferentation” that plastic changes of frequency representation can occur on a short timescale of a few hours. They suggest that probable candidates to account for these findings may be changes in the efficacy of existing excitatory synapses or modification of synaptic efficacy by transcription of immediate early genes. They do not suggest axonal sprouting and dendritic growth to be involved because this may require more time.

Molecular signals direct differentiation, migration, process outgrowth and synapse formation during the earliest steps of development. Neural activity is needed to refine the connections further so as to forge the adult pattern of connectivity. The neural activity may be generated spontaneously, especially early in development, but later depends importantly on sensory input. In this way, intrinsic activity or sensory and motor experience can help specify a precise set of functional connections (Kandel and Squire, 2001).

On the other hand, plasticity may also be the fundamental reason for the reported improved results in auditory perception after specific auditory stimulation as suggested by Johansen (1984, 1986, 1988, 1992, 1998).

It can be argued that music and language are homologous functions that evolved from a common ancestor that embodied their shared features and that certain features are still shared (Brown, 2001).

Moore *et al.* (2003) concluded that the central auditory problems induced by OME seem likely to contribute to learning and social difficulties esperienced by some children with chronic OME. Early intervention to eliminate the hearing loss produced by OME is desirable, if effective therapies can be implemented. Auditory training to improve listening performanc may accelerate recovery following chronic OME.

Kujala *et al*. (2004) reported data showing that long-term exposure to noise has a persistent effect on central auditory processing and leads to concurrent behavioral deficits. They found that speech-sound discrimination was impaired in noise-exposed individuals, as indicated by behavioral responses and the mismatch negativity brain response. Furthermore, irrelevant sounds increased the distractibility of the noise-exposed subjects, which was shown by increased interference in task performance and aberrant brain responses.

Based on the results from an intensive research project Richardson *et al.* (2004) suggested that individual differences in auditory processing skills are related to individual differences in the quality of phonological representations, reading and spelling. They furthermore suggested that the accurate detection of supra-segmental cues are more important for the development of phonological representations and consequently literacy than the detection of rapid and transient cues.

Neuroscientists Lu, Manis and Sperling from Univ. of Southern California have found that “noise” (snow on a computer screen) seems to impede figure/ground discrimination in dyslexic individuals. They think that difficulty extracting the signal from noise is a general problem by dyslexics in other sensory/perceptual areas as well (Emerson, 2005).

A RETROSPECTIVE PROGRAM EVALUATION STUDY

The Training program

Over a period of 3-18 months the students at the Sensomotoric Centre in Mjölby, Sweden listen for 10-15 minutes daily to specially composed and individually formatted music tapes. The amplitude of each recording is manipulated (lowered or raised) via a 1/3 octave band equalizer to partly compensate for the variation between the measured hearing thresholds and the optimum curve suggested by Gulick (1971) and Tomatis (1963, 1991). For all frequencies, where the hearing is more sensitive than the optimum curve indicates, the amplitude is reduced by 60% of the variation between the actual hearing and the optimum curve. For frequencies where the hearing is poorer than the optimum curve indicates, the amplitude is raised by 40% of the variation between the two curves. The music is formatted separately to each ear. Generally in all right handed and in the majority of left handed students, the sounds to their *right ears* are boosted the most.

The music used has been specially made for this purpose (Holbech, 1986) and covers the frequency range 100 Hz to 16 000 Hz. In this way AM- as well as FM- and TM-sensitivity is trained.

The students’ hearing is reviewed at regular intervals (every 6^{th} – 10^{th} week), and new individual tapes or CDs based on the follow-up assessments are formatted and utilized during the following stimulation period.

For the first 6-8 weeks the stimulation is primarily addressing the frequency range 100-2000 Hz. For the remaining stimulation period the frequency range 1000-16000 Hz is targeted.

The purpose of this study

Taken together the reported results from the Sensomotoric Centre at Mjölby (Sohlman, 2000) and the published research has raised these questions:

1) Is there a correlation between the total variation of the individual’s hearing curves and the optimum hearing curve and the number of discrimination errors found by dichotic listening?

2) Can specific auditory stimulation (with individually formatted music) influence auditory laterality and hearing sensitivity and thus the variation between the hearing curve and the optimum curve?

3) Is a reduction in variation between the individual’s hearing curve and the optimum curve obtained by specific auditory stimulation followed by a reduction in discrimination errors found by dichotic listening?

4) Is the length of the stimulation period and reductions in errors correlated?

METHOD

Participants

In Mjölby fourteen files (m: 13; f: 1) were randomly drawn from a file containing the total number of cases (N=127) completing the programme between Jan. 1997 and April 2000 . The small sample was chosen due to expected large effect size based on earlier pilot studies. All turned out to be right handed and the mean age was 10yr10m (9;1-13:7). One student had dropped out before finishing the stimulation program. All students had normal hearing according to standard hearing tests (20 dB screenings). All students had been referred by school or by parents based on tests for delayed reading (two or more years behind age matched peers) and spelling problems (dyslexia).

The mean stimulation period for the reported study was 29 weeks (10 - 65). The students had listened to the individualized tapes at home and had been supervised by their parents according to guidelines from the Sensomotoric Centre.

Controls

Twenty four age-matched students (f: 15; m: 9) with above average reading skills (teachers' assessments) from a comprehensive school served as controls. All of these were tested with the same DL (dichotic listening)-test (DLCV-108 NF, Hughdal & Asbjørnsen, 1990) as the research sample. (NF indicates the Non-Forced condition part of the test with 36 simultaneous pairs of CV syllables).

Auditory Laterality Index (ALI)

Based on the DL-tests an auditory laterality index (ALI) was calculated for all participants: *ALI = (R-L)x100/(R+L)*, where R indicates the number of correct responses via the right ear and L indicates the number of correct responses via the left ear. The students in the contol group (N=24) had a mean ALI of +21.78 (*SD*=15.47). Only one student in this group (a left-handed girl) had a negative ALI (-2.86). The other left-hander in this group (a boy) had an ALI of +5.88.

Mean ALI for the right-handed girls (N=14) was +21.17 (*SD*=13.57) and for the right-handed boys (N=8) the mean ALI was +27.92 (*SD*=14.11).

RESULTS

Tomatis (1963) suggested an ascending hearing curve from 15-20 dB at 125 Hz to $^{-}5$ -$^{-}10$ dB at 3000-4000 Hz with stabilization at this level and a slight drop in the higher frequencies (6000-8000 Hz) to be the optimum curve for analysis of music and language. This optimum curve was found also by Gulick (1971) and was used as a measure in this study.

1) Before intervention the total variation (sum) in dB at eleven frequencies between the measured hearing thresholds for both ears and the optimum hearing curve was calculated for each individual in the research group and correlated with the number of errors by dichotic listening in the non-forced condition (DLCV-108 NF). The correlation was moderately negative (-.49).

This may indicate that initially a slight to moderate variation between the actual hearing and the optimum hearing in some individuals is more damaging to auditory acuity than a more profound variation approaching a small hearing loss or alternatively hypersensitivity.

2) Files from only six of the thirteen students in the research group had enough data to deal with questions 2, 3 and 4 above. (Results from post intervention DL were not available for seven students).

These six students were all right-handed males with mean age of 10yr01m (9;10-10;04).

Auditory Laterality

Before intervention the mean ALI in these six students was +3.49 (*SD*=23.00). Mean ALI after stimulation was +29.09 (*SD*=18.23). *d* (effect size) = 1.24. (According to Cohen (1988) a *d* above **.**80 is a large effect size).

Before stimulation two students had ALI < 0. After stimulation all had ALI > 0.

Hearing threshold

The mean variation from the optimum curve for the six hearing curves (R + L) before stimulation was 205.00 (*SD*=54.16). After stimulation the mean variation from the optimum curve was found to be 122.50 (*SD*=39.44). *d* = 1.76.

For the total group of thirteen students who completed the stimulation period the mean variation (R+L) from the optimum curve was reduced from 220.38 (*SD*=75.77) to 143.46 (*SD*=77.12). *d* = 1.00.

After 19 weeks of stimulation one of these students had no alterations in hearing sensitivity at the right ear (variation from the optimum curve before and after was 230, which appeared to be the largest variation in the sample). Variation in his left ear improved from 210 to 155 (reduction in variation between curves).

(It may be important to note that in earlier clinical trials the left ear has shown the most rapid improvements followed later by the right ear.

This may be related to better myelination of the neuronal fibers in the right hemisphere or to the known earlier maturation of the right hemisphere especially in boys (Geschwind and Galaburda, 1987; Korpilahti, 1996).

Research has shown a greater neural activation over the right temporal lobe when people are exposed to dichotically presented musical stimuli (Hughdal *et al.*, 1999).

(It is known that musically unskilled people usually exhibit greater activation over the right temporal lobe while listening to music, whereas skilled musicians exhibit greater activation over the left temporal lobe.

Could the observation referred above indicate also a similar change in listening mode, when an individual has been listening to the same tonal patterns every day for several weeks?)

By the remaining twelve students their right ears alone had a mean variation from the optimum curve of 87.92 (*SD*=15.61) before the stimulation period and of 57.08 (*SD*=18.31) after stimulation. *d* = 1.82.

Thus 92.3 per cent had a raised auditory sensitivity from stimulation of hearing during the training period with a large effect size.

t test for dependent means (repeated measures design): $t(11) = -12.210$; $p < .01$, one tailed.

This study would appear to show that specific auditory stimulation has an effect on auditory laterality and on hearing sensitivity. Generally auditory laterality became more right biased and auditory sensitivity was reduced in the low frequency range (< 1000 Hz) and increased in the high frequency range (> 1000 Hz).

Discrimination of language sounds

For the six students with all data available the mean error rate by DL-NF before the stimulation period was 33.33% (*SD*=13.05). After the stimulation period the mean error rate was 14.00% (*SD*= 9.24). *d* =1.73. The mean error rate for the age matched controls was 13.50% (*SD*=6.13)

3) For these six students the reduction in total variation (R + L) between the actual hearing curves and the optimum hearing curve correlated with reduction in errors by DL-NF at *r*=**.**19.

This is a minor correlation, but contrary to the previous suggestion that the variation between the actual hearing curves and the optimum curve is negatively correlated with errors at DL-NF and thus with hearing sensitivity.

Looking at the right ears only in these six students it was found that the mean variation between the actual and the optimum hearing curve was reduced from 88.33 (*SD*=15.72) to 57.50 (*SD*=20.56). *d* = 1.70. The correlation between the reduction in variation between the actual hearing curves and the optimum curve for the right ears only and the reduction in errors by DL-NF was found to be **.**68.

This study would suggest that reduction in variation between the actual hearing curve and the optimum hearing curve for the right ear alone (altered sensitivity) after specific auditory stimulation was related to improved auditory acuity.

Length of stimulation period

4) For the six students with a complete set of filed data the stimulation periods varied from 21 weeks to 65 weeks (mean 29 weeks). The reduction in error rate by DL-NF correlated with length of stimulation period (*r*= **.**86).

Reading measures

Parents and children involved in this study reported that reading and spelling had improved more than expected, but this was not thoroughly tested due to lack of resources. (The children in this study were living in different parts of Sweden).

In a report published by *A Chance To Grow/New Visions School* (2001) it was stated that a group of 50 students following a similar HSAS program at NVS during the school year 2000/2001 made an average gain of 1.56 years on the Gates-MacGinitie test (measuring vocabulary understanding and reading comprehension skills), while the students at NVS who did not participate in this program made a **.**93 year gain on this test.

DISCUSSION

CAPD is generally not assessed by basic means such as audiometry, binaural audiometry and dichotic listening. Assessments of dyslexia do not include audiometry. The possible link between auditory problems and later reading difficulties is still disputed even though a great proportion of contemporary research confirms that there is a link. Ongoing research at several sites may expand our knowledge in this field.

The reported results from the clinical work in Mjölby (although the number of participants in this retrospective study is limited) indicate that assessment procedures utilizing such simple tools as audiometry and dichotic listening may provide valuable information about the auditory difficulties of a Language Impaired (LI) – and later dyslexic - child. At the same time they can provide the necessary information for a remedial technique of which listening to specially composed and specially recorded (individually formatted) music is an essential part.

This does not mean that problems related to specific reading difficulties are not found in other areas (coordination problems, left right confusions, sequencing problems, several problems related to vision, problems with postural control and primitive reflexes to mention some). As shown in other research projects (Zeffiro and Eden, 2000) and documented by Bein-Wierzbinski (2001), Goddard (1996), Nicolson and Fawcett (1994, 1995, 1999), Sohlman (2000), and by Stein (2001) such problems are certainly there.

Stimulation programs

For more than half a century many special education teachers, clinicians, speech-language therapists, ENT-practitioners and others have experienced that LI children often face subsequent reading and spelling problems in school.

In an attempt to help LI children develop their language properly, some of these individuals have independently developed assessments and stimulation programs motivated by positive outcomes but without generally accepted theories. Some of these have been used for many years.

During the fifties and early sixties the Danish/American researcher, Christian A. Volf (1894-1967) developed a stimulation method based on the assumption that deficient auditory perception (poor AM-, FM- and TM-sensitivity) was at the root of many children's reading problems. C.A. Volf focussed on these three sound parameters: the amplitude, the spectral and the temporal aspects of sound (the parameters characterizing the formants), and developed records with soundtracks to stimulate the auditory system in these areas (Johansen, 1984).

Even though Volf did not write a single paper on his method of stimulation, it has survived as a private business in Denmark and in Germany, due mainly to reported positive outcomes and despite limited published research and limited advertising, and performed by educators and therapists that were trained by Volf.

The psychologist Karen L. Skjølstrup, in her Master's Thesis (1989) reported interviews with some former clients of C.A. Volf and their successful outcomes from this type of auditory stimulation. But few researchers have been interested in pursuing these ideas.

The method used in the Mjölby-project reported above is inspired by C.A. Volf's method, but the use of modern techniques has made it possible to make individualized stimulation programs.

The much disputed work by Paula Tallal and Michael Merzenich (*FastForWord* ™) (Hook, Macaruso and Jones, 2001; Macaruso and Hook, 2001), relies on ideas similar to those expressed by C.A. Volf more than forty years ago (Johansen, 1986), but there are major differences in the ways that these ideas are implemented in the training programs.

Today we know that deficient auditory perception may cause language problems including problems in reading and spelling. We also know that the plasticity of the neural networks makes it possible successfully to utilize stimulation programs following brain injury, the results of which just a decade ago seemed to resemble pure magic.

The study presented above seems to support C.A. Volf's view that subtle auditory problems can cause language problems - but more importantly than that: we can do something about it!

Recently Habib *et al*. (2002) have reported positive results from three studies using temporo-phonological training very similar to the methods used by Paula Tallal providing further justification for a rational, indication based temporo-phonological treatment of dyslexia.

Definitely phonemic awareness is a prerequisite for learning an alphabetic writing system. Therefore phonemic awareness must be explicitly taught in all proper courses for beginning readers and in remedial reading courses (where language sounds must be mapped to letter symbols). (McGuinness, 1997). But some individuals do not benefit from this teaching.

The development of phonemic awareness may be hampered by minor and unrecognized auditory processing problems. In some individuals these difficulties may well be related to poor perception af amplitude modulation, frequency modulation and temporal modulation of single formants, the "atoms" of the language "molecules" (the phonemes).

THE NEED FOR RESEARCH

Ramus (2001) is arguing strongly that the locus of the phonological deficit seen as a core deficit in dyslexia must be related to the sub-lexical phonological representation: "Firstly, word learning involves (among other things) storing a word's phonological form in the phonological lexicon. The only way the phonological lexicon can receive such information is through the sub-lexical phonological level: if the latter is deficient, then the former is likely to become so. In particular, if certain phonological features are misrepresented or under-specified at the sub-lexical level, there is little hope that this will improve in the lexicon." (Pg. 206). And: "If dyslexic children have deficient sub-lexical phonological representations to begin with, should they not have difficulties acquiring the phonology of their native language? This prediction remains largely untested." (Pg. 208).

(Also read "The Scientist in the Crib" (Gopnik, Meltzoff and Kuhl, 1999).

Similarly Goswami (2002) is arguing "any deficits in phonemic awareness are products of the preexisting poorer phonological skills in dyslexic children." (Pg. 154).

We suggest that initially basic problems in the *acoustic representations* may cause faulty sub-lexical phonological representations at least in some dyslexic individuals.

In order to address language discrimination problems it seems of major importance to look at the significance of the right ear, to search for reduced hearing (sensory deprivation) in the right ear during early childhood, and to look carefully at the present hearing in the right ear. We know how essential inputs via the right ear are for the decoding of language sounds (Kuhl *et al*., 2001; Stirling *et al*., 2000). Knowing as we do that language areas in the left hemisphere show less activity in the dyslexic brain than in the non-dyslexic brain and knowing the significance of the contralateral ear, we should take more heed of these factors in relation to language development. Stimulation through music/sounds that are easy to manipulate makes it possible to target the specific parameters of the formants (amplitude, frequency and temporal features) that constitute the basic acoustic features in language as well as in music.

Research employing mismatch negativity (MMN) suggests that the neural representation of these parameters within the auditory cortex are spatially separate (Giard, Lavikainen, Reinikainen *et al.*, 1995).

Recent MEG and PET data (Tervaniemi *et al.*, 2000) indicate that the earliest auditory processing stages do not differ between speech and music sounds.

Plastic changes in the brain as a result of computer-based training of dyslexic children that were accompanied by reading improvement has recently been demonstrated by the Cognitive Brain Research Unit at the University of Helsinki (Kujala *et al.*, 2000).

Korpilahti *et al.* (2002) reported from a similar stimulation program as the one used in Mjölby (10 min./day through 9 months) that they found "Better discrimination of consonants and development of naming skills. In these skills the ADT/*(HSAS)*-group reached the reference values for the age. Parents and teachers reported noticeable progress in attentive and language skills in those children whose ERPs were normalized after the training. … ADT/*(HSAS)* training can be used to reach better auditory discrimination and, by that means to help the LI child to acquire language."

In the Report of the National Reading Panel (NICHD, 2000) it is recommended that reading programs should cover five domains 1) phonological awareness and in 2) phonics in reading and writing, and work on 3) fluency, 4) vocabulary and 5) comprehension. The results presented in this paper would indicate a sixth "domain" prior to these five: 0) secure adequate auditory processing (AAP).

Testing for and targeting deviant responses with stimulation may be a valuable new research area for training or rehabilitation of individuals with milder perceptual disorders such as CAPD and – dyslexia?

We need to undertake more research and to develop more neuro-educational training programs to address these problems!

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