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Possible Effects of Specific Auditory Stimulation (Johansen-IAS) on Language Development of a Group of Dyslexic Students

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Abstract: A group of dyslexics with auditory processing difficulties showed significant improvements in language skills following intervention using non-linguistic auditory stimulation to enhance sensitivity and obtain a 'healthy' right ear advantage. Twenty–eight participants aged thirteen to seventeen years were divided into three groups: a dyslexic intervention group, a dyslexic control group and a non-dyslexic control group. The intervention used was Johansen Individualised Auditory Stimulation (Johansen IAS). The intervention group listened individually for ten minutes daily over fifteen to eighteen months to CDs of computer-generated music customised according to the results of their hearing tests. Improvements in technical reading (decoding) and spelling abilities in the dyslexic intervention group support a link between basic sensory perception skills and language-related skills at a phonological level. The study supports the use of non-linguistic auditory stimulation to optimise auditory perception, and the notion that such interventions benefit language in dyslexics whose auditory sensitivity and laterality is atypical. Further research is suggested to investigate the link between fundamental auditory processing abilities and our ability to learn and process language. The importance of assessing basic auditory perception, and the potential for its 're-education' to optimise phonological awareness (widely accepted as a crucial process in literacy) is highlighted.

Keywords: Auditory Stimulation, Developmental Dyslexia, Improving Language Abilities, Phonological Awareness, Johansen IAS, Music

1. Introduction

It is widely accepted that dyslexia has many hidden features which may be present in the absence of overt reading and spelling problems, the best known features of which are difficulties with phonological awareness, verbal memory and verbal processing speed.

There are several approaches to the identification of the underlying deficits in dyslexia. The phonological approach suggests a problem with the analysis of speech sounds (an individual's ability to attend to, recognise and store components of actual language), which affects phoneme segmentation and the ability for effective grapheme-phoneme mapping (Bradley & Bryant; Vellutino; Snowling; Ramus, Rosen, Dakin et al [1-4]). An alphabetic spelling system relies on the effective representation, storage and retrieval of grapheme-phoneme correspondences, and these researchers showed that if components are poorly represented to start with reading and literacy will be affected. Frith and Snowling [5] isolated a difficulty in phonological, but not lexical or semantic processing tasks as cause for a particular difficulty in processing non-words (which relies purely on grapheme-phoneme mapping rather than allowing for compensation through lexical or semantic reasoning). Specifically, a dysfunction of the left-hemisphere perisylvian brain area is indicated, distorting the effectiveness of phonological representations, and phonological and orthographic correspondences.

To explore the view of a fundamental difficulty with processing sounds effectively, it is worth considering the observation of consistent patterns of activity in dyslexics across cultures (Paulesu, Demonet, Fazio et al) [6], despite variations in the phonological structure of languages and in societal attitudes to learning disabilities. According to a review by Grigorenko [7] the implication of a phonological deficit as central to dyslexia, and the difficulties with automation that contribute to reading difficulties, appear to be universal across different languages. Grigorenko suggests that pronounced weaknesses occur in phonological processing in phonologically complicated languages (such as English) whereas in languages that are phonologically more simple (such as German) difficulties with the skills underlying automation are implicated in the manifestation of dyslexia. This illustrates two areas of weakness (phonological and automation) which are contributors to language and present as weaknesses in dyslexics, but appear to characteristically compensate for each other in dyslexic profiles.

Further research looks specifically at the auditory or perceptive difficulties that might underlie characteristic phonological deficits. Tallal, Miller & Fitch and Merzenich, Jenkins, Johnston et al [8, 9] found children with dyslexia showed difficulty differentiating between rapidly changing consonant-vowel syllables presented at a normal rate. Tallal [10] concluded that the ability to process sounds in this way is vital for normal acquisition of language, phonological awareness and reading skills, and that deficits may result in impaired language skills including reading. However, there is much debate concerning the deficits observed and whether they are language-based (Studdert-Kennedy) or attributable to a more general auditory disorder as suggested by Tallal. More recently, Gaab, Gabriela, Deutsch et al [11, 12] observed neural response to rapid auditory stimuli and reported that this is disrupted in children with dyslexia, and can be improved with training.

The suggested link between auditory processing and speech and language difficulties is not yet fully understood, but evidence exists that general weakness in the identification of speech sounds is one of the causal factors in poor reading skills (Clark and Richards) and that such difficulties are related to family history (Benasich, Thomas & Choudbury). Wright, Lombardino, King et al [13-15] 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 the tone. They concluded that temporal and spectral specificity, of the auditory perceptual deficits reported, may serve to guide the search for the underlying neural bases of language disorders. In a longitudinal study, Boets, Wouters, Van Wieringen & Ghesquiere [16] found that young children showing literacy impairment after their first year of school were likely to have experienced deficits in phonological awareness, rapid automised naming, speech-in-noise perception and frequency modulation detection at pre-school level (before receiving any formal literacy instruction) suggesting a causal relationship between these deficits and disrupted literacy development.

So, whilst dyslexia can present as many forms of language difficulty, relating to comprehension, attention, phonological skills and so on, it is reasonable to suggest that some dyslexics with phonological coding difficulties may have an auditory processing disorder or perceptual difficulty, which has disrupted their language acquisition, and that observation of this relationship can help towards discovering effective interventions.

2. Theoretical Background

2.1. A Developmental Auditory System

It is known that the cortical structures involved in communication are developmental and continue to change for several years after birth (McCall and Plemons). It is also well documented that, as according to the dynamic dual pathway model of auditory language comprehension, successful processing arises from a dynamic interaction between the left and right hemispheres (Friederici & Alter) [17, 18].

The corpus callosum (the axon pathway responsible for effective cross-hemisphere interaction) develops from birth through neural maturation. It is suggested that auditory experience strengthens the pathway between hemispheres, meaning that exercises encouraging transfer can form a valuable intervention (Musiek, Kibbe & Baran) [19]. This kind of intervention has the advantage that it does not need to involve linguistic content, and can therefore be beneficial even to very young children.

The left hemisphere has been shown as localised for language functions in most people, although studies comparing the effects of suppressing language regions in left and right hemisphere dominant individuals, by transcranial magnetic stimulation (TMS), have shown language functions to reside in the right hemisphere in some individuals (Knecht, Flöel, Dräger. et al.). Broca first showed impaired production of speech following damage to the left inferior frontal cortex. Localisation of language production to the left hemisphere has been supported by more recent study of brain activity using fMRI. For example, Pujol, Deus, Losilla et al [20-22] observed the frontal cortex during silent word generation and found activity lateralised to the left hemisphere in 96% of right-handers, with right hemisphere lateralisation in only 10% of left-handed subjects.

A classic study by Wernicke [23] showed that a patient with damage to the left posterior superior temporal lobe struggled with language comprehension. More recent studies comparing spoken language, signed language and non-linguistic gesture have indicated that the left hemisphere functions dominantly when dealing with linguistic content or meaning (Corina, Vaid & Bellugi; Levanen, Uutela, Salenius & Hari). Sininger & Cone-Wesson [24-26] concluded after a study with 1593 infants that stimulus guided asymmetry is at the level of the cochlea before it is evident in the auditory cortex. They also concluded that initial processing of sound in the auditory system at the level of the cochlea and brainstem may serve to facilitate later development of hemispheric specialization for sound processing. As input to the right ear is directly processed in the left hemisphere, the development of a dominant right ear (lateralisation), which would send information directly to the left hemisphere, could be expected to lead to more accurate and efficient processing of verbal stimuli. Recent research has demonstrated that our right and left ears behave differently in response to different kinds of auditory information, showing increased otoacoustic emissions in our right ears in response to speech-like sounds, and in our left ears for music-like tones (Sininger et al) [26]).

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, Coffey-Corina, & Neville). Helland and Asbjørnsen [27, 28] found that dyslexic children showed a deviant asymmetry pattern compared to a control group, with a weaker response pattern to right ear stimuli than controls. Children, particularly those with language impairment, have also been found to show major left ear deficits (Musiek, Kibbe & Barran) [19]. Dichotic listening skills (necessary when ears are simultaneously exposed to different auditory information) are dependent on inter-hemispheric transfer of information. Dichotic listening ability has been shown to be a predictor of reading performance (Näslund, Johansen and Thoma) and instrumental in identifying dyslexics (Moncrieff & Musiek) [29, 30], suggesting a link between this level of auditory processing and dyslexia in some cases, as well as to general auditory processing disorders.

2.2. A System Adaptive to or Enhanced by Experience

We now know that the organization of the cortex can be shaped or altered by experience: Yarrow et al. [31] found that physical skill-learning led to massive increases in the neural connections in the primary motor cortex, in rats and humans. Professional musicians (who practice many hours per week) have shown larger cortical representation of left hand fingers than non-musicians (Pascual-Leone et al; Elbert, Pantev, Wienbruch et al. More recently, in a longitudinal study of 6-year-old children who undertook 15 months of instrumental musical training, Hyde, Lerch, Norton et al [32-34] showed changes to the motor cortex, but also to the auditory system and corpus callosum, when compared to controls receiving no training. This evidence suggests that neural structures underlying language may be strengthened by training.

2.3. Effects of Sensory Deprivation

In the past, it was widely thought that the sensory cortex matured early in life and thereafter had a fixed organization and connectivity. Leviton and Bellinger [35] concluded on the basis of a meta-analysis of several studies that there is a convincing association between early and persistent otitis media (causing periods of sensory deprivation) and later reduction in language function as measured by paraphrase quality. Freeark et al [36] measured the effect of variable otitis media, experienced in the first 3 years of life, on the verbal ability of 3-4 year old's. They found that the negative effects were ameliorated in children who typically participated in active and engaging parental verbal stimulation. These studies suggest that maturation of language-related auditory functions rely on exposure to sounds as a part of a developmental process (in line with theories of neuroplasticity previously discussed).

Evidence discussed here leads to questions of the 'malleability' of an auditory system and whether indeed this system can be honed and improved through specialized exposure to auditory stimuli. There is a suggestion that certain forms of auditory stimulation serve to enhance auditory perception in a way that can go some way to make up for sensory deprivation, or delayed or disrupted development. Bruer and Greenough [37] describe a model of neuroplasticity that allows for 'experience-expectant' plasticity (incorporating fundamental development of the auditory system) and 'experience-dependent' plasticity (responding to dynamic experience throughout life that enhances the expectant development). This model also can raise questions about sensory experiences that may optimize auditory development (Whitelaw and Yuskow) [38].

2.4. Auditory Processing

Children with periods of unilateral hearing loss have been shown to perform less well in school, including in terms of behavior in the classroom (Cho Lieu) [39] and the presence of a right ear deficit was observed as an additional risk factor. 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) [40]. Their results confirmed that children with right ear impairment perform significantly poorer than their left-ear-impaired counterparts especially in verbal subtests that are sensitive to minor input/processing damages.

Research has 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 (Wright et al; McArthur & Bishop). Rosen [15, 41, 42] concluded, following a review of the available literature, that auditory processing deficits do occur in association with language disorders, but that there is not a yet a proven causal link. Wright et al [15] concluded that the temporal and spectral specificity of the auditory perceptual deficits reported might serve to guide the search for the underlying neural bases of language disorders.

Although we describe evidence of auditory processing difficulties which occur and seem to lead to literacy difficulties in children with dyslexia, it should still be considered that an absence of auditory processing deficits amongst dyslexics has also been reported (Griffiths & Snowling; Heath, Hogben & Clark; Hill, Bailey, Griffiths, et al [43-46]). The specific nature of auditory deficits apparent in some dyslexic individuals is also inconsistent and still under debate. It is therefore suggested that there are various profiles of language disorders and dyslexia, with varying underlying causes, but that a focus on improving auditory processing skills could still be beneficial for these groups.

2.5. Stimulation for Improvement

Although incomplete, the recent developments in understanding our auditory perceptual abilities, their development, their disruption and their relation to language ability, have led some clinicians, educators and researchers to suggest that it may be possible to train or stimulate the auditory system in individuals with language problems in such a way that their perceptual abilities improve, and that such stimulation after some time may also have an effect on language (Merzenich, Jenkins, Johnston, et al; Tallal, Miller, Bedi et al; Treharne [9, 47-48]). Many methods of remediation aim to improve the ability to process sounds relevant to phonological coding. This can be through intensive phonological and oral language training, or, as newer approaches suggest, through more fundamental means of improving attention to sounds and ability to deal with them efficiently.

We have already discussed one example in relation to otitis media (Freeark et al) [36]. In relation to our discussion of the prevalence of left or right ear weakness, research has shown dichotic listening exercise to be beneficial to weaknesses in either ear by gradually strengthening the response following intensified stimulation to the weakened ear (Musiek & Schochat,[49]. This indicates the possibility of developing right ear dominance in order to optimize processing of auditory information.

Tallal, Stark, Kallman et al [50] concluded that many academic problems associated with language are a result of auditory perceptual impairments, particularly in temporal aspects of sound recognition. A subsequent area of interest was the effective use of acoustically modified speech, and adapted neuroplasticity training, to improve language processing (Tallal et al and Merzenich et al [47, 9]). This conclusion led to a focus on strengthening the relevant neural pathways through modified presentation of acoustic stimuli (Tallal & Merzenich). Moncrieff & Wertz (2001) [51, 52] trained children with left ear deficits intensively in two phases of dichotic listening training. In phases I and II, children showed improved dichotic listening after training. A promising additional finding was that by phase II, subjects were also showing significant improvements in language comprehension and word recognition.

2.6. Use of non-language Stimuli

Researchers have pointed out that language and music share many features as forms of information (Patel; Koelsh). Both involve the processing of rules and memorised information, and the systems that observe these features in music and language have been shown to correspond in studies of brain activity (Miranda & Ullman) [53-55].

Koelsh, Gunter, Von Cramon et al [56] played chord sequences to subjects and found that the cortical network thought to be domain-specific for language processing (the areas of Broca and Wernicke, the superior temporal sulcus, Heschl's gyrus, both planum polare and planum temporale, as well as the anterior superior insular cortices) was activated in response to unexpected musical changes in these sequences. In a study by Forde Thompson, Schellenberg & Husain [57] musical training was associated with superior performance, and matched greater ability to extract prosodic information from spoken phrases, suggesting shared neural resources.

Musical training is known to modify cortical organisation, as previously discussed. Schlaug, Norton, Overy et al found changes in brain structure and cognitive development in children after 15 months of violin lessons. Treharne [58, 59] also found children with enhanced musical experience through a music playtime group had superior language comprehension compared with their peers, and this was related to rhythmic ability which is also related to reading. Wong, Skoe, Russo et al [60] examined encoding of linguistic pitch in musicians and non-musicians. Their research showed that, regardless of actual musical talent, those who played a musical instrument demonstrated more robust encoding of language than those who did not. This study highlights a shared subcortical function for elements of music and language. Also, as the musicians tested were not regarded as ‘exceptional musical talents’, who one might suggest have some innate ability for the processing in question, this study suggested that the exposure to musical training has a positive effect on linguistic processing ability. Following on from this research, Musacchia, Sams, Skoe, et al [61] showed that such manipulation can extend to the subcortical structures involved in processing speech. The results showed a relationship between amount of musical practice and sensory encoding of auditory and audiovisual information.

Research has shown that the processing of prosodic phrasing, which could be seen as the ‘musical’ element of speech, is as important for sentences rich in linguistic content as for those with little or no semantic, syntactic or phonemic information (Pannekamp, Toepel, Alter, et al). Based on the results from an intensive research project, Richardson, Thomson, Scott et al [62, 63] 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 is more important for the development of phonological representations and consequently literacy than the detection of rapid and transient cues.

Wallace found that perception of the prosodic element of speech aids memory for 10 month old babies, suggesting that this enhancement of memory is a prerequisite for language. Interestingly, Bellis [64, 65] summarised that Prosodic Deficit is frequently related to reading and spelling difficulties that are in turn related to right-hemisphere processing, but that phonological decoding skills remain intact. Perhaps being open to a richer experience of linguistic information, prosodic elements and pitch provide a more substantiated phonemic representation.

The Tomatis method is an example of a therapy that has been shown to successfully improve language related skills through exposure to musical auditory stimulation. A meta-analysis of 5 studies concluded significant improvements in linguistic, cognitive, auditory, psychomotor and social skills following this programme of therapy (Gilmor) [66].

3. Johansen Individualised Auditory Stimulation

This study observes the effects of the use of a particular auditory stimulation therapy on dyslexic pupils. With the premise that ‘healthy’ development involves gradual organisation of the auditory processing system, encouraged by natural exposure to auditory information, Johansen Individualised Auditory Stimulation (JIAS) aims to retrain elements of frequency perception that may have been delayed or starved of the necessary stimulation during development (leading to auditory processing difficulties and consequent literacy difficulties). The musical stimulation that is prescribed is customised (in terms of specific frequency stimulation and encouraging a dominant ear) to the strengths and/or weaknesses of an individual’s auditory perception, dictated by an initial assessment of pure tone audiology. As well as restoring a subject’s attention to frequencies in general, the programme also aims to encourage a right ear advantage, as we have discussed in relation to optimum processing of auditory information.

The current study aims to provide evidence that the principles used by Johansen Individualised Auditory Stimulation successfully optimise auditory perception, and create a right ear advantage in dyslexics whose development may have been delayed or disrupted leading to auditory processing deficits and subsequent language impairments. In addition, it is expected that these developments will coincide with improvements in language related skills, in particular technical reading (decoding) and spelling.

3.1. Participants

There were 28 participants aged 13 to 17 years (19 boys and 9 girls) all of whom attended the same independent high school in Holland. They were divided into 3 groups: Dyslexic Intervention Group (Group 1), Dyslexic Control Group (Group 2), Non-dyslexic Control Group (Group 3). The nature of the intervention was discussed with parents and pupils. Groups 1 and 2 were matched according to age, sex and their performance on technical reading (decoding), reading comprehension, spelling and mathematical calculation. The results of which were taken from their school files. Group 1 (the treatment group) was selected from the pool of pupils who stated that they were willing to listen for 10 minutes a day through the full training period and where the parents agreed to supervise.

Group 3 was matched according to age and sex with groups 1 and 2

Group 1 - (N=10, 7 boys and 3 girls)

Group 2 - (N=10, 7 boys and 3 girls)

Group 3 - (N=8, 5 boys and 3 girls)

Groups 1 and 2 had been diagnosed as dyslexic according to criteria of the Netherlands Dyslexia Foundation (Stichting Dyslexie Nederland).

Group 3 consisted of non-dyslexic children.

Participants and their parents gave consent to take part in the study.

A Bonferroni Multiple Comparison test and an ANOVA were used to analyse the data from participants’ school files in the following areas: technical reading (decoding), reading comprehension, spelling and mathematical calculation. The tests found no significant variance between Group 1 and Group 2 in technical reading/decoding or spelling, but found significant differences in these skills between Groups 1 and 2 and Group 3.

Prior to intervention each participant was tested individually.

3.2. Assessments

IQ tests

GIVO: Groninger Intelligence Test for Continued Education. (Van Dijk & Tellegen) [67] The Groninger Intelligence for Continued Education Test is a widely used, Dutch IQ test.

Scores: Total, verbal and performance IQ measures were used.

Laterality:

Group 1: 7 right handers, 1 left hander and 2 ambidextrous.

Group 2: 10 righthanders

Group 3: 5 right handers, 1 lefthander and 2 ambidextrous.

In all groups, the following skills were tested before and after the period of intervention All groups were tested with the same tests:

Technical Reading

Technical reading / decoding

EMT: One-minute Test (Brus & Voeten) [68]

Pupils are asked to read as many words as possible within one minute, from a vertical list of regular Dutch words. Score: total number of correct words.

Klepel: (Bos van den, K. P.,) [69] Non-word test. Participants are asked to read as many non-words as possible within 2 minutes. Score: total number of correct words.

Silent Reading Test: Henneman, Kleijnen, Smits [70] Participants are asked to read text aloud for 2 minutes. Score: total number of correct words minus errors and corrections.

Reading Comprehension

HACQUEBORD-TEST: Hacquebord [71] Five texts with multiple-choice questions. The results are ranged in micro-, meso and macroscore. The microscore is on word-level, the mesoscore on sentence-level and the macroscore on text-level

Spelling

“The wonderful weather”, from ‘Protocol Dyslexia Continued Education.’ Henneman, Kleijnen, Smits [72] Participants write down 8 sentences dictated to them (average 16 words per sentence).

Score: total number of errors

Writing / copying

Writing / copying task: 'Protocol Dyslexia Continued Education.' Henneman, Kleijnen, Smits [73] Participants copy as much as possible from a 13 word sentence in two minutes. Score: total number of correct words.

Auditory Memory

Digit Span Test. Schenk, Van Luyn-Hindriks & Nieuwenbroek [74]. A series of sets of 4, 5, 6 and 7 digits are read to the participant, to be reproduced in correct order after a pause of 2-3 seconds. A series of sets of 3, 4, 5 and 6 digits are read to the participant to be reproduced in reverse order after a pause of 2-3 seconds. If the participant makes three errors in succession at any point, they move on to the next series.

Score: total number of correct digits.

Visual Memory

Schenk, Van Luyn-Hendriks & Nieuwenbroek [75]

Participants are shown series of 3, 4 and 5 cards (24 in total) showing symbols (circle, square, cross, triangle). The cards are shown for 2 seconds each, and the participant has to draw them.

Score: total number of correct reproductions.

Phoneme Analysis

Van Luyn-Hindriks [76] The participant is read a non-word, then asked to repeat the word, omitting the first, second or last sound. 20 words in total.

Score: total number of errors.

Rapid Naming

Van den Bos, et al [77]. Participants are asked to name aloud the contents of 50 cards in order, as fast as possible. Cards include the following:

Dice: name the number of dots

Pictures: name the object (tree, fish, chair, bucket, bed)

Colours: name the colours (black, red, yellow, green, blue)

Numbers: name the numbers (5, 7, 3 etc.)

Letters: name the letters (d, h, g etc)

Words: read the words (3 – 4 letter words)

Colour names: read the colour names of the previously used colours

Picture names: read the object names of the previously used pictures

Score: time taken per item, in seconds (total time divided by 50). Errors and corrections are registered but not calculated in the score.

Audiometric Testing

Audiograms to assess precise threshold values were recorded before and after the intervention period.

Dichotic Listening

The dichotic listening test consisted of five sets of 20 CVC non-words or pairs of words, to be repeated by the participant immediately after listening. 1) 20 non-words to the right ear 2) 20 non-words to the left ear 3) 20 pairs of words (different word to each ear) where the participant is asked to focus attention to the right ear 4) 20 pairs of words (different word to each ear) where the participant is asked to focus attention to the left ear 5) 20 pairs of non-words (different word to each ear) where the participant is asked to repeat both words. Instructions were given orally by the tester before each set.

Score: Number of correct words via each ear

Questionnaires

All parents of the Group 1 participants completed an ABC questionnaire before and after the period of auditory stimulation (A=attention, B=behaviour and C=concentration). Answers were on a 5 point scale.

All participants of Group 1 filled out an automation questionnaire. The questions were related to non-language automation problems. Answers were given on a 5 point scale.

3.3. Treatment Group

Group 1 took part in a period of Johansen Individualised Auditory Stimulation (Johansen IAS) which involved the following procedures.

3.4. Technical Equipment

Audiometric assessments were carried out using a computer-based, calibrated audiometer developed by Mediacenter in Mjölby, Sweden. The audiometer is run on an Acer Travel Mate 662LCi, using Telephonics TDH-39P earphones. Calibration showed less than 0.1% deviance on any frequency and less than 0.5% deviance on any dB level. Also on the computer is a dichotic listening test developed by Baltic Dyslexia Research Lab, known as the Johansen Dichotic Listening Test.

Sensograph (SG) software, also developed by Mediacenter, is used to customize and create the treatment CDs.

3.5. Method of Stimulation

Informed by the results of the audiometric assessment, a customized CD of selected music is created on the computer. The audiometric data are transported to a built-in equalizer (part of the SG) that adjusts automatically so that the amplitude for each frequency, in each ear, is lowered or raised to fit pre-programmed reference values.

In the recording process the SG uses pre-programmed threshold levels as reference values, referred to as the optimum hearing curve, OHC: 125 Hz: 20dB, 250 Hz: 15 dB, 500 Hz: 12 dB, 750 Hz: 10 dB, 1000 Hz: 5 dB, 1500 Hz: 0 dB, 2000 Hz: -5 dB, 3000 Hz: -10 dB, 4000 Hz: -10 dB, 6000 Hz: 5 dB, 8000 Hz: 0 dB

If hearing at a given frequency is more sensitive than indicated by the reference value then the amplitude for this frequency is reduced by as much as 60% of the difference between the reference value and the threshold value found in the pupil. If hearing at a given frequency is less sensitive than indicated by the reference value then the amplitude for this frequency is raised by as much as 40% of the difference between the reference value and the threshold value found in the pupil. To secure smooth frequency adjustments in between the measured frequencies, Q-values of 7.0 are used in the 10 channel built-in equalizer in the SG. The adjustments are made separately for the right and the left ear, but normally for right handed children there is a pre-programmed 5dB extra bias in the right ear to support the development of a right ear advantage (REA). This bias may be removed or reversed for some lefthanders.

After a period of 8-12 weeks the pupil is re-assessed and a new recording following the same principles is made. Some pupils will need 3-4 CDs, others will need as many as 8-10 CDs.

Each pupil in Group 1 listened to a number of individually customized CDs in periods of 8-12 weeks. Listening to the CD took place via stereo earphones at home for 10 minutes a day. The pupil listened in a relaxed state either sitting or lying down. For this study all participants used Sennheiser HD477 headphones. In this pilot study the average number of CDs used was 8, with an overall intervention period of 15 to 18 months.

3.6. The Music

The music used has been designed especially for Johansen Sound Therapy by Bent-Peder Holbech and Kjeld Johansen and has been in use since 1984. The basis of all the Johansen Sound Therapy music is seven 10 minute pieces, known as ‘Waves’. Each ‘Waves’ has been especially composed to stimulate a different frequency band covering approximately 1½ octaves. Mood, pulse and tonality have also been taken into consideration and additional features may be added as indicated by the individual’s audiometric and functional profile.

Each individual CD used in the study was customised (in terms of specific frequency stimulation and encouraging a dominant ear) according to the data from the subject’s pure tone audiogram. Each of the subjects’ individual CDs was selected to cover the range of frequencies observed to be furthest from the Optimum Hearing Curve in their most recent pure tone audiogram. The music was taken from single ‘Waves’ pieces or a combination of selected components from more than one ‘Waves’ piece. Some CDs had additional enhancements to emphasise ear dominance or inter-hemispheric integration. Post-intervention re-assessment for all groups took place when Group 1 had completed the intervention, approximately 18 months after initial assessment.

4. Results

Descriptive statistics for the three groups are presented in Table 1.

Table 1. *Participants' age and IQ.*

Average	group 1	group 2	group 3
Age	14.03	14.02	14.00
Total IQ	97.1	98.4	96.5
verbal IQ	95.4	96.3	99.3
Performance IQ	98.6	106.0	95.9

Gp 1: Dyslexia intervention group (n=10)
Gp 2: Dyslexia control group (n=10)
Gp 3: Non-dyslexia control group (n=8)

Differences between the groups at pre-test

Performance of the three groups at the first assessment (pre-test) was compared using one-way analysis of variance (ANOVA). If a statistically significant ($p < .05$) or approaching significance ($p \leq .10$) result was obtained, pairwise comparisons between the groups was carried out using Games-Howell post-hoc test.

The three groups did not differ significantly on auditory processing skills (audiogram as well as left and right dichotic listening), see Table 2. In terms of literacy skills, significant differences were observed on the One Minute Test, non-word test, text reading and spelling (but not writing or reading comprehension), see Table 3. Group 3 was significantly or near-significantly better than Groups 1 and 2 ($p \leq .10$). The differences between Group 1 and Group 2) were relatively small and were not significant.

In terms of rapid naming, the groups differed significantly on the letter naming task, where Group 3 significantly outperformed Group 1 (but not Group 2). In three further cases (naming of numbers, words, colour names) Group 3 produced the best scores, though its advantage over Groups 1 and 2 usually fell short of statistical significance on the post-hoc test, see Table 4.

The three groups also differed significantly on visual memory, and near significantly on auditory memory. It was, again, Group 3 that did best, although its advantage over Groups 1 and 2, as indicated by the post-hoc test, was not significant or only approaching significance, see Table 4.

Finally, the three groups differed significantly on phoneme analysis, where Group 3 significantly outperformed Groups 1 and 2, see Table 4.

Overall, the two subgroups of children with dyslexia (Groups 1 and 2, intervention and control) appeared well matched; none of the pairwise differences between them were even approaching statistical significance. On the other hand, both dyslexia groups were clearly worse than the non-dyslexic control group (Group 3) on most (though not all) measures of literacy, and the only measure of phonological awareness (phoneme analysis). Groups 1 and 2 also tended to be somewhat lower on most measures of rapid naming, though the differences usually fell short of statistical significance. There was also some trend for the dyslexic groups to do less well on the visual and auditory memory.

Table 2. *Participants' auditory processing skills.*

		Pre-test				Post-test				Follow-up[1]			
		M	Mdn	SD	Min-Max	M	Mdn	SD	Min-Max	M	Mdn	SD	Min-Max
Audiogram	Gp 1	248.5	245	55.1	180-335	81.5	70	25.8	55-125	86.3	85	20.7	60-120
	Gp 2	213.5	202.5	33.6	180-285	202.0	205	39.3	145-270	-	-	-	-
	Gp 3	236.3	232.5	46.1	185-310	219.4	197.5	49.0	175-295	-	-	-	-
Dichotic listening-L	Gp 1	83.3	85	6.9	73-95	84.4	84	5.3	74-92	89.8	91.5	4.9	80-95
	Gp 2	75.8	77.5	10.5	60-92	79.0	80	4.4	74-88	-	-	-	-
	Gp 3	78.0	78	3.7	72-84	79.5	81	5.6	70-86	-	-	-	-
Dichotic listening-R	Gp 1	81.6	82	10.7	55-93	90.2	90	4.3	84-96	92.4	93	3.5	87-90
	Gp 2	83.1	84.5	5.8	71-90	84.0	83	4.7	78-90	-	-	-	-
	Gp 3	82.8	85	7.3	68-90	86.5	90	7.6	70-92	-	-	-	-

Note: The values for the audiogram results are the variation from the optimum hearing curve (described above). Lower Audiogram scores indicate that the hearing curve is closer to the Optimum Hearing Curve.
Higher 'Dichotic Listening – R' scores indicate increased right ear dominance.
[1] n=8 (two participants were lost at the follow-up)

Table 3. *Participants' literacy skills.*

		Pre-test				Post-test				Follow-up[1]			
		M	Med	SD	Min-Max	M	Med	SD	Min-Max	M	Med	SD	Min-Max
One Minute Test (no. of correct words)	Gp 1	65.1	64.5	11.4	52-85	73.6	74.0	10.3	59-95	81.5	78.5	8.5	71-92
	Gp 2	57.1	59.0	15.6	30-76	59.9	57.5	10.0	43-74	-	-	-	-
	Gp 3	80.5	79.5	14.6	66-110	86.6	88.0	17.6	66-109	-	-	-	-
Nonword test (no. of correct words)	Gp 1	41.2	40.0	13.8	23-63	52.6	56.5	15.6	28-74	61.4	61.0	15.3	37-81
	Gp 2	32.4	35.0	11.6	16-53	35.3	39.0	11.9	15-46	-	-	-	-
	Gp 3	69.6	66.5	23.2	45-111	66.0	62.0	20.0	44-105	-	-	-	-
Test reading (no. of correct words)	Gp 1	208.4	204.0	54.0	117-321	235.9	234.5	52.4	150-341	267.0	263.0	39.0	220-335
	Gp 2	198.3	201.5	34.6	142-237	211.2	217.5	29.5	166-254	-	-	-	-
	Gp 3	283.6	251.5	75.9	213-404	281.3	271.5	65.6	208-380	-	-	-	-
Spelling (no of errors)	Gp 1	20.5	17.0	13.5	3-44	12.4	12.5	8.8	1-27	5.9	4.5	4.9	0-15
	Gp 2	28.1	24.0	19.4	5-64	23.8	24.0	13.3	6-48	-	-	-	-
	Gp 3	9.8	7.0	6.2	5-21	10.0	8.0	7.9	3-27	-	-	-	-
Writing (no of correct words)	Gp 1	32.5	33.5	5.7	19-39	35.7	36.0	6.3	19-39	38.3	38.5	4.5	32-45
	Gp 2	32.4	33.5	6.2	20-43	34.5	35.5	5.1	20-43	-	-	-	-
	Gp 3	38.0	34.0	11.0	25-54	38.3	37.0	7.6	25-54	-	-	-	-
Reading comprehension (total score)	Gp 1	62.0	64.0	10.7	41-77	66.9	64.5	13.7	46-88	70.9	74.0	11.4	49-84
	Gp 2	61.3	62.0	13.2	36-82	66.7	69.5	11.4	49-80	-	-	-	-
	Gp 3	55.0	50.5	10.3	43-73	61.4	56.0	12.0	50-82	-	-	-	-

Note: The spelling test measures number of errors, hence a decrease in scores indicates an improvement
[1] n=8 (two participants were lost at the follow-up)

Table 4. *Participants' rapid naming and phonological awareness skills.*

		Pre-test				Post-test				Follow-up[1]			
		M	Med	SD	Min-Max	M	Med	SD	Min-Max	M	Med	SD	Min-Max
Rapid naming – dice	Gp 1	.58	.54	.11	.43-.75	.54	.51	.09	.43-.75	.50	.47	.11	.42-.77
	Gp 2	.54	.52	.10	.43-.78	.54	.54	.08	.44-.78	-	-	-	-
	Gp 3	.51	.50	.10	.39-.69	.48	.49	.05	.43-.69	-	-	-	-
Rapid naming – pictures	Gp 1	.84	.82	.13	.68-1.05	.77	.76	.10	.65-.95	.72	.69	.13	.56-.92
	Gp 2	.77	.78	.12	.52-.96	.71	.67	.11	.54-.89	-	-	-	-
	Gp 3	.75	.73	.14	.58-1.04	.71	.69	.12	.57-.88	-	-	-	-
Rapid naming – colours	Gp 1	.86	.78	.19	.70-1.19	.74	.74	.08	.62-.87	.74	.68	.15	.58-.97
	Gp 2	.78	.73	.20	.51-1.21	.75	.72	.13	.53-1.01	-	-	-	-
	Gp 3	.70	.68	.08	.60.82	.66	.69	.08	.53.74	-	-	-	-
Rapid naming – numbers	Gp 1	.53	.52	.12	.35-.70	.47	.45	.08	.38-.61	.43	.41	.08	.37-.60
	Gp 2	.51	.50	.06	.43-.63	.50	.51	.05	.42-.58	-	-	-	-
	Gp 3	.44	.44	.06	.37-.55	.41	.40	.07	.32-.50	-	-	-	-
Rapid naming – letters	Gp 1	.57	.60	.10	.38-.70	.52	.52	.08	.37-.63	.50	.51	.11	.34-.68
	Gp 2	.53	.54	.09	.38-.62	.49	.51	.06	.38-.59	-	-	-	-
	Gp 3	.45	.45	.08	.35-.60	.42	.42	.07	.34-.54	-	-	-	-
Rapid naming – words	Gp 1	.56	.56	.10	.43-.74	.49	.51	.07	.39-.59	.44	.42	.06	.38-.58
	Gp 2	.54	.52	.09	.40-.67	.53	.51	.07	.42-.64	-	-	-	-
	Gp 3	.46	.46	.06	.39-.53	.43	.44	.07	.34-.53	-	-	-	-

		Pre-test				Post-test				Follow-up[1]			
		M	Med	SD	Min-Max	M	Med	SD	Min-Max	M	Med	SD	Min-Max
Rapid naming – colour names	Gp 1	.54	.55	.10	.36-.66	.52	.51	.08	.40-.64	.47	.45	.09	.37-.64
	Gp 2	.52	.54	.08	.38-.63	.52	.53	.06	.42-.61	-	-	-	-
	Gp 3	.45	.45	.06	.36-.52	.43	.41	.06	.38-.53	-	-	-	-
Rapid naming – picture names	Gp 1	.50	.51	.08	.36-.63	.48	.49	.09	.36-.60	.43	.41	.07	.36-.57
	Gp 2	.48	.48	.08	.37-.60	.48	.49	.06	.37-.57	-	-	-	-
	Gp 3	.43	.41	.07	.34-.57	.42	.40	.05	.36-.50	-	-	-	-
Auditory memory (no. correct)	Gp 1	11.1	11.5	3.3	6-16	12	12	4.11	7-22	15.8	13	7.42	9 - 32
	Gp 2	12.3	12.0	3.6	8-18	13.4	13	2.07	10-16	-	-	-	-
	Gp 3	15.5	16.5	5.4	6-22	15	15	3.46	9-20	-	-	-	-
Visual memory (no. correct)	Gp 1	10	10.5	3.0	4-15	13	13	3.13	8-18	15.1	14	3.0	12-21
	Gp 2	11.9	11.5	2.0	9-16	14.3	13.5	3.74	9-20	-	-	-	-
	Gp 3	13.9	14.	3.6	7-18	14.75	15	3.33	10-19	-	-	-	-
Phoneme analysis (no. of errors)	Gp 1	6.2	6	2.9	1-11	3.5	3.5	1.5	1-5	2.13	2.00	.64	1-3
	Gp 2	5.7	4.5	3.9	0-11	5.3	4.5	3.4	2-11	-	-	-	-
	Gp 3	1.8	1	1.5	0-4	2.6	2.5	1.6	1-5	-	-	-	-

Note: The phoneme analysis measures number of errors, hence a decrease in scores indicates an improvement.
[1] n=8 (two participants were lost at the follow-up)

The effects of intervention were investigated using a mixed-design factorial analysis of variance (ANOVA), with a between-subject effect of Group (measured at three levels: Group 1, Group 2 and Group 3), and a within subject effect of Time (measured at two levels: pre-test and post-test). This analysis was carried out separately for each variable (See reference [1]). A successful intervention should result in Group 1 improving its performance significantly more than the two control groups; a pattern that, statistically, would correspond to a significant interaction between Time and Group. It was this interaction, therefore, that was a focus of our analyses, see Table 5.

The results of ANOVA analyses are summarized in table 5.

Table 5. *Summary of factorial ANOVA analyses of the dependent variables.*

Variable	Main effect of Group: F(2,25)=	Main effect of Time: F(1,25)=	Group by Time interaction: F(2,25)=
Audiogram	5.790, p=.009	200.985, p <.001	129.055, p <.001
Dichotic listening-L	4.512, p=.021	1.440, p=.241	0.170, p=.844
Dichotic listening-R	0.430, p=.655	7.903, p=.009	2.210, p=.131
One Minute Test	8.398, p=.002	20.836, p <.001	1.826, p=.182
Nonword test	10.374, p=.001	8.123, p=.009	11.869, p <.001
Text reading	5.245, p=.013	17.918, p <.001	8.011, p=.002
Spelling	3.920, p=.033	12.527, p=.002	4.274, p=.025
Writing	1.230, p=.309	5.085, p=.033	1.045, p=.366
Reading comprehension	0.905, p=.417	7.636, p=.011	0.044, p=.957
Rapid naming – dice	1.234, p=.308	2.944, p=.099	1.346, p=.278
Rapid naming – pictures	1.335, p=.281	13.023, p=.001	0.193, p=.826
Rapid naming – colours	2.162, p=136	9.525, p=.005	2.328, p=.118
Rapid naming – numbers	3.196, p=.058	9.551, p=.005	1.888, p=.172
Rapid naming – letters	5.231, p=.013	5.787, p=.024	0.158, p=.855
Rapid naming – words	3.863, p=.035	10.213, p=.004	3.123, p=.062
Rapid naming – colour names	4.217, p=.026	1.393, p=.249	0.317, p=.731
Rapid naming – picture names	2.402, p=.111	0.976, p=.333	0.156, p=.857
Auditory memory	2.976, p=.069	0.498, p=.487	0.469, p=.631
Visual memory	2.161, p=.136	18.551, p <.001	1.595, p=.223
Phoneme analysis	4.486, p=.022	2.732, p=.111	5.386, p=.011

Five significant and one near-significant interactions were observed; they are analysed in the order of strength:

Audiogram. Paired sample t-tests revealed that the significant Group by Time interaction occurred since the improvement from pre-test to post-test was much greater in Group 1 (t[9]=16.332, p <.001) than in Group 2 (t[9]=2.203, p=.055; a difference only approaching significance) and in the Group 3 (t[7]=2.409, p=.047). Before intervention, the three groups did not differ significantly (as mentioned in the previous section). This changed after the intervention: now, Group 1 significantly outperformed both Group 2 and Group 3 (See reference [2-27]). Average deviance from the optimum hearing curve had reduced, see Figure 1.

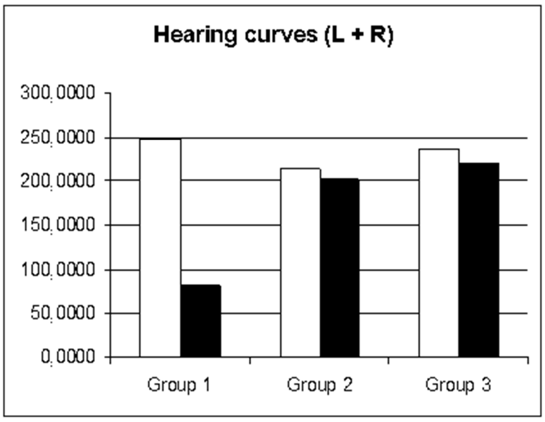


Figure 1. *Hearing Curves.*

Score: Sum of distance in dB at 11 frequencies of L and R ears from the optimum curve before and after intervention.

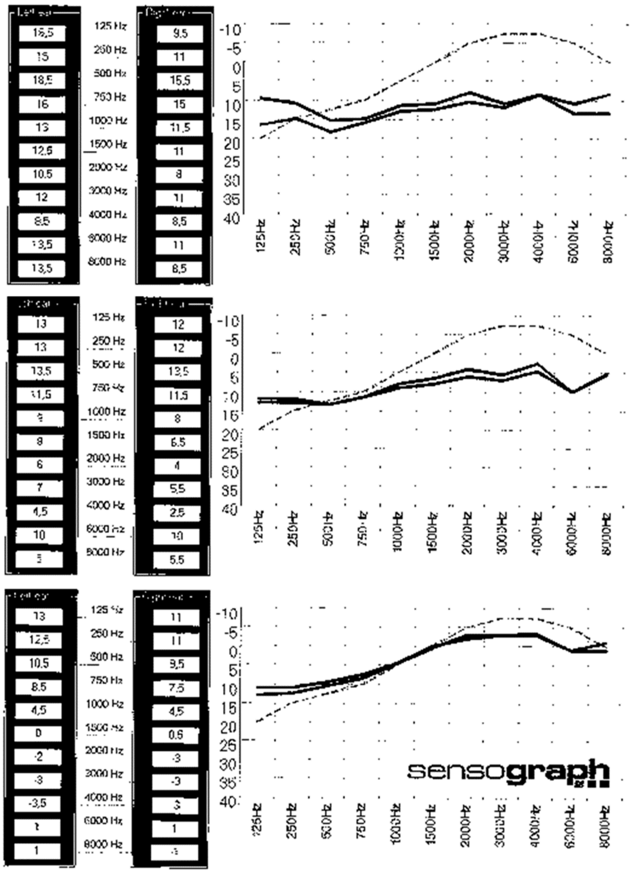
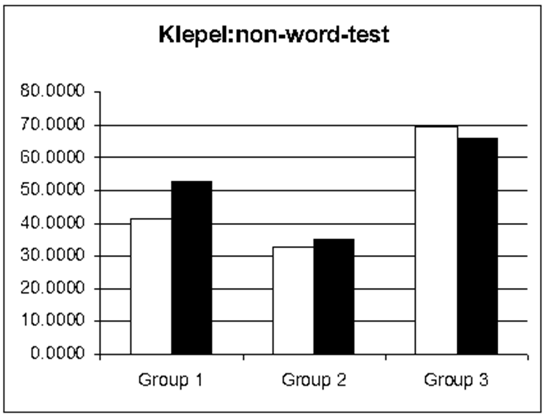


Figure 2. *Average Audiograms.*

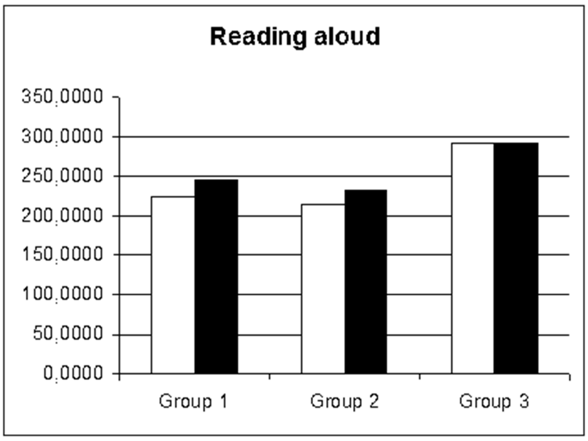
Nonword test. There was a significant performance improvement in Group 1 (t[9]=9.544, p <.001). Group 1 significantly outperformed Groups 2 and 3 after intervention. Group 2 made a non-significant improvement and Group 3 declined.

Text reading. There was a significant improvement in both Group 1 (t [9]=5.577, p <.001) and Group 2 (t[9] 3.911, p=.004). The advantage of Group 3 over Group 1 was no longer significant (p=.283).



Score: Number of correct words

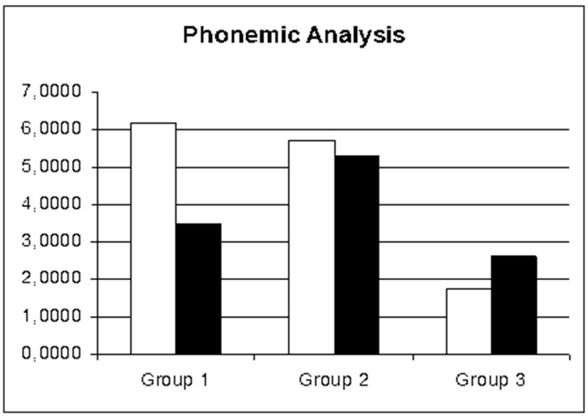
Figure 3. *Klepel Non-Word Test.*



Score: Number of correct words

Figure 4. *Reading Aloud.*

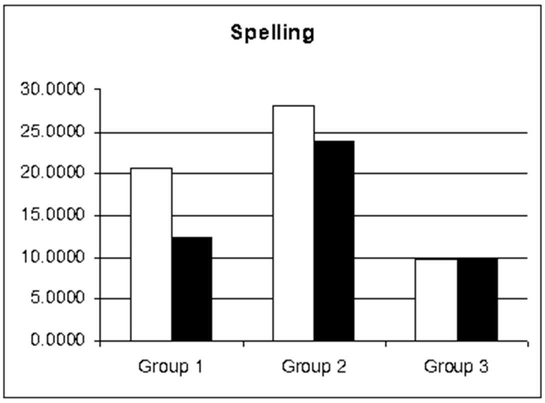
Phoneme analysis. There was a significant improvement in Group 1 (t[9]=3.059, p=.014). Before the intervention, Group 3 significantly outperformed both Group 1 (p=.002) and Group 2 (p=.029). After the intervention, this advantage was reduced and no longer statistically significant (p=.481 and .104, respectively).



Score: Number of errors

Figure 5. *Phoneme Analysis.*

Spelling. Group 1 showed a significant improvement (t[9]=4.290, p=.002). Following the intervention, Group 3 were still significantly better than Group 2 (p=.039). The advantage of Group 3 over Group 1 was no longer significant (p=.818). Before the intervention, the two dyslexia groups were well matched (p=.576), but following the intervention Group 1 showed a near-significant advantage (p=.092).

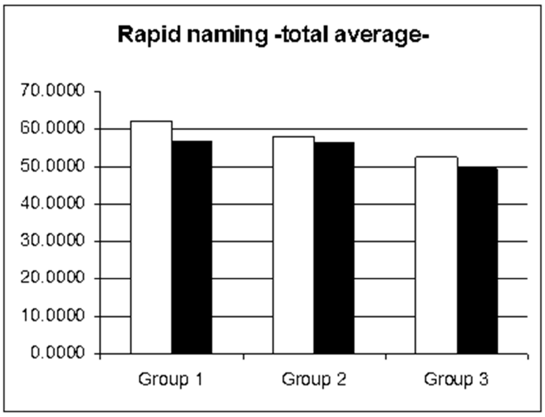


Score: Number of errors

Figure 6. *Spelling.*

Rapid naming of words. Group 1 showed a significant improvement (t[9]=3.151, p=.012). Following the intervention, the advantage of Group 3 over Group 1 was no longer significant (p=.245), but Group 3 were significantly better than Group 2 (p=.022).

To sum up, the statistical analysis provided some evidence for specific effects of intervention, most clearly with respect to audiogram, but also non-word reading, phoneme analysis spelling and rapid naming of words. The evidence was ambiguous with respect to text reading, where Group 1 improved only marginally more than Group 2. With respect to other variables, there was no evidence for a specific effect of intervention: improvement over time was usually apparent (as reflected by the significant main effect of Time, see table 4), but all groups improved to similar degree.



Score: Time in seconds per item

Figure 7. *Rapid Naming of Words.*

Follow-up data was collected for the intervention group only (Group 1), so was not included in this analysis. However, it is worth mentioning that in all instances where the specific effects of intervention were observed, the gains of Group 1 were maintained or even improved over time.

Probabilities are normally written as *p*=<.01 or .05 or .005 or .001 anything less than 5 in 100 i.e .05 occurring by chance is considered as non-significant. However I do agree that when you are nearly at .05 it might be clinically /educationally valid to note this especially if the period of intervention is relatively short.

Always refer to the relevant table in the text. Never presume a reader will find the right one unless you do refer specifically to it by number, similarly with charts.

5. Discussion

A premise of this study is that during development, our auditory processing systems are gradually organised, helped by auditory experience and inter-hemispheric transfer of information, to reach an optimum state for processing crucial sounds – in particular those that are language-related for literacy development. In addition, research has shown that interventions involving auditory stimulation can lead to improvement in language-related skills (Merzenich et al; Tallal et al, Treharne [9, 47, 48]). It is suggested that a period of carefully controlled non-linguistic auditory stimulation, through optimisation of the sensitivity and organisation of the auditory system, will lead to improvement in the language-related skills of certain dyslexics. Some studies have focused on temporal aspects of language sounds (Merzenich, Schreiner, Jenkins et al and on the categorical perception of vowel sounds (Bertucci, Hook, Haynes et al) [78, 79] as areas of difficulty influencing phonological skills and language development. However, although recent work has identified dichotic listening ability and right ear dominance as related to language function (Helland et al) [28], few studies have successfully linked basic auditory perceptual skills or ear advantage as influencing factors in the language impairments experienced by certain groups of dyslexics, in a way that pinpoints these fundamental skill sets as key to remediation. For the purpose of this study language refers to written language, although it is accepted that written and spoken language share a common basis.

In addition, the authors believe that much research to date has attempted to assess remediation techniques by addressing a heterogeneous category of developmental dyslexia with an assumed common cognitive deficit of some kind. Therefore, a study that uses assessment to ensure homologous groups and treats specifically according to a known deficit is beneficial to the literature.

The controlled nature of the intervention used in this research project provides a robust choice for a controlled study. As well as being tailored for each participant's needs, the process of the intervention follows each pupil's customised plan and adjusts accordingly in order to achieve a consistent outcome in the basic skills being improved. It is hoped that these benefits go some way to diminish the effect of individual difference, an issue that affects studies of dyslexia so commonly, in the specific area of auditory perception and will contribute to a clearer view of the importance of these skills in relation to language impairments experienced by some dyslexics.

For Group 1 (the dyslexia intervention group), following the period of intervention, statistically significant improvements in auditory sensitivity (documented by altered audiograms) accompanied statistically significant improvements in technical reading (decoding). spelling, phonemic analysis and rapid naming. Not only do these results confirm that auditory sensitivity can be trained and improved through auditory stimulation, but also that these basic level sensory abilities relate to the phonological and language-related abilities of some dyslexics. It is suggested that by improving the participants' ability to process sounds effectively, their ability to deal with phonological coding improves, leading to improved performance on language tasks. It is possible that concentration, attention and motivation for tasks are improved as less stress is incurred by linguistic stimuli, boosting confidence.

Both Group 1 and Group 2 (the dyslexia control group) showed significant improvements in text reading, with only a slightly better improvement made by Group 1. It is possible that although underlying processing skills had improved following treatment, actual text reading would take longer to improve than could be shown within the period of this study.

It is generally agreed that auditory processing deficits occur at least in some dyslexic individuals. Questions exist over the origin of these deficits– are they speech specific, related to automation abilities, a result of slow temporal processing or linked to poor working memory? The current study observes non speech-specific auditory perception and demonstrates the effect of intervention using non speech-specific auditory stimulation. This investigation of such basic level auditory ability brings into play the issue of laterality and right ear dominance, already shown to be related to language skills in dyslexics (Helland et al, Moncrieff & Black [28, 80]).

The findings of the present study support theories of a relationship between dichotic listening ability and language related skills in dyslexics. The treatment group made significant improvements in dichotic listening tasks, accompanied by significant improvements in technical reading (decoding), spelling, reading aloud, phonemic analysis and rapid naming.

The only areas where Group 2 showed statistically significant improvements were in visual memory and rapid naming of letters. These results may suggest that merely taking part in pre and post-test assessments encouraged higher scores or perhaps that confidence was increased on a second turn at the tests. Dyslexics have been shown to make use of visual strategies to aid reading and spelling that are key to language ability (Plaza & Cohen; Valdois, Bosse & Tainturier)[81, 82]) so the possibility that these improvements were a result of the participants' own continually developing strategies is worth consideration.

Certain factors in this pilot study would benefit from improvement, and further research. The fact that Group 1 were the only group to take part in the intervention may have led to greater effort if they realised they were expected to improve. However, Group 2 were also receiving structured extra support in school as a result of their dyslexia, yet showed no significant improvement at post-test in comparison to Group 3 receiving no remediation. We hope that the motivational effect resulting from awareness of expectations was therefore not too influential between groups 1 and 2, but further research might control for this effect by introducing some form of 'dummy' intervention known not to affect the relevant measures.

The participants were all pupils at the same independent high school, and it was fairly challenging to find a sufficiently large group of pupils in one school who were willing to commit to such a lengthy intervention. Some pupils required extra encouragement to complete the listening tasks, and it could be argued both ways that this would contribute to positive or negative effects on post-test performance. Nevertheless, it is reassuring that the structured and controlled intervention led to significant improvements despite a demanding regime.

6. Conclusion

This study shows significant improvements in language skills in a group of dyslexics shown to have auditory processing difficulties, through a method of intervention that successfully uses non-linguistic auditory stimulation to enhance sensitivity and obtain a 'healthy' right ear advantage. Improvements in technical reading (decoding) and spelling abilities in Group 1, support a link between basic sensory perception skills and language-related skills at a phonological level.

The study supports the use of non-linguistic auditory stimulation to optimise auditory perception, and the notion that such interventions benefit language in groups of dyslexics whose auditory sensitivity and laterality is atypical.

Dyslexia continues to pose many questions relating to its definition, cause, variation and remediation. Whilst this study does observe the effects of Johansen IAS on dyslexic pupils, rather than making bold claims about the underlying causes or definition of dyslexia, it strengthens the case for further research to investigate the link between our fundamental auditory processing abilities and our ability to learn and process language. An interesting perspective to take forward is that if we leave the complex arguments regarding the sensory, cognitive and phonological profiles of dyslexics to one side, there is a clear and concise benefit to considering the importance of carefully assessing and, as we have seen is possible in this study, re-education of basic auditory perception, to optimise phonological awareness, widely accepted as a crucial process for progress in literacy. Further, if we continue to find that improvements in phonological awareness and language skills occur in association with better attention, decreased stress for the learner and improved concentration and confidence, many more interesting and potentially informative links may emerge.

Study limitations

Findings in this study are subject to a number of limitations. The sample size was small and may not be reflective of all dyslexic students in the Netherlands. The Johansen program only relates to auditory perception of non-verbal stimuli (music) and not to words. This could have possibly stimulated a pattern of normalisation at an even more basic level. There are no follow-up measurements for the control groups. Only the research group has been tested afterwards. There is no control over a possible placebo effect. There can be assumed that special attention of whatever sort may also have an effect. The theoretical introduction is based on different sources. Some of them may show theoretical and empirical weaknesses. With this publication there is tried to prove that improvement of auditory perception may affect reading, spelling and information processing in general.

Follow-up data were not included in this analysis, as they were collected from the dyslexia intervention group only. Between group differences before and after intervention were investigated using one-way ANOVA with Games-Howell post-hoc tests.

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