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Music-related Auditory Stimulation and Phonological Working Memory

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Abstract: At first glance, children with language impairments are difficult to understand, which is why speech therapy tends to focus on pronunciation. Upon closer inspection, however, the impairment is often based on deficiencies in speech comprehension, phonological working memory and phoneme discrimination skills. Despite their importance for successful learning at school, working memory capacity and speech comprehension are still not components of conventional speech therapy. In this experiment, 92 preschool-aged children with deficiencies in speech comprehension and working memory were observed for a period of 15 weeks. Considering that working memory has in the past been considered unresponsive to speech therapy, the evaluation study focused on proving this to be achievable through music-related auditory stimulation. The children were divided into three groups. The experimental group (n=32) took part in auditory stimulation with technically modulated music for a period of 12 weeks. The special-attention group (n=31) was assisted in school activities for a similar period. The third group (n=37) served as a waiting list control group. The children in the experimental group showed significantly improved working memory capacity and better phoneme discrimination skills compared to the control groups. The findings of the study suggest that music-related auditory stimulation can support children with language impairments and improve their chances at school.

Keywords: Music-related Auditory Stimulation, Phone Discrimination, Preschool Children, Speech Comprehension, Working Memory

1. Introduction

When it comes to children's chances of doing well at school, working memory capacity ranks higher than intelligence quotient [1]. According to one comprehensive survey, something like 10% of each school intake have a working memory which is not conducive to learning and can lead to frustration and behavioural difficulties. The working memory capacity of a five-year-old gives a good indication of that child's likely school grades six years later. Teachers tend to regard these children as daydreamers, as unmotivated and lacking in intelligence [1].

The phonological loop as a component of working memory is basic to a child's linguistic development [2, 3]. In Baddeley's working memory model [2, 4], phonological loop and visuo-spatial sketchbook are subordinate to, and in constant contact with, a central executive. It is from there that information makes its way into the long-term memory [5]. Children with SLI have a limited phonological short-term memory (PSTM) and the deficits in their phonological ability and capacity of PSTM appear to show no change despite speech therapy [6]. Deficiencies in phonological ability and phonological working memory remain unchanged even in children who started talking late (*late bloomers*) and whose spontaneous speech seems unremarkable [7].

Speech production is conditional on speech receptivity [8, 9]. Conventional speech therapy, however, generally focuses on expressivity. Deficiencies in speech comprehension are often ignored so long as there is nothing untoward about the child´s pronunciation and he/she acts normally in everyday situations [8]. There are indications that deficiencies in reading comprehension result from problems in speech comprehension in preschool-aged children [10] and that substandard reading comprehension has an adverse effect on arithmetic comprehension at elementary level [11]. Teachers of the children involved in this study tended to believe that the children just could not or did not want to listen [12, 13] which corresponds to Alloway's findings.

There are not many studies which deal with speech therapy methods and how well they work [14]. The auditory training described in this article builds on the author's experience of working with music-based methods; this is something the author has used for many years to underpin her speech therapy, and is admittedly somewhat controversial [15, 16]. It seems logical however to boost language skills with auditory stimulation (i. e. with music). Neuroscientific research and objective measurements have produced considerable evidence of the positive effects of music and music-making on language skills [17, 18]. There are structural similarities in language and music. Additionally, music and language are processed in part in the same or overlapping brain regions [17, 19, 20].

2. Learning and Development

According to Lurija, the functional units of the brain that develop successively form the basis of learning and development (Figure 1). These units are interactive and interdependent. Any deficits in the functions on a lower level will affect the functions on the next highest level [21].

The phonological working memory falls within the second unit. Short-term and working memory storage is particularly important for vocabulary acquisition, comprehension and syntax, as core language knowledge is built up on the strength of the data retained in the memory [3].

While it is true that receptive capability is seen as the basis for speech production, and comprehension problems often remain undetected [13], therapeutic methods are generally targeted at expressive speech [8, 9], i.e. the third functional unit in Lurija's model. It seems reasonable, though, to take a closer look at therapy options that focus on the lower levels.

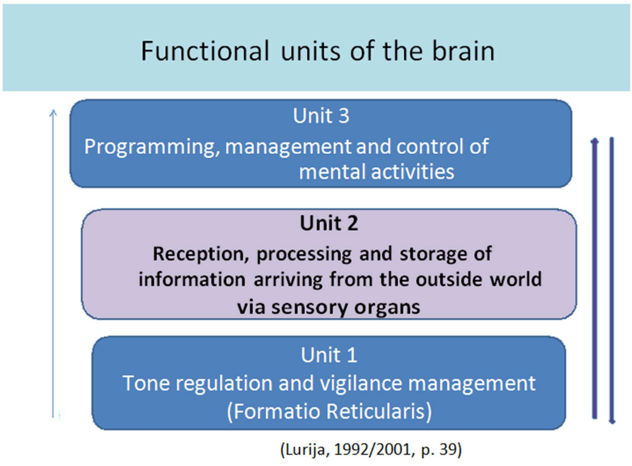

Figure 1. *Functional units of the brain.*

3. Language and Music

3.1. Structural Common Ground

Phones comprise a number of formants, i.e. frequency bands of maximum intensity, which correspond to the resonances produced by musical instruments [22]. A phone is made up of the sum total of its formants, corresponding to one or more resonances. They are normally measured in vowels, as these are the best researched, and as the automatic analysis procedures are best suited to them [23].). German vowels are each based on four formants: the first two of these formants are the crucial elements in terms of identification and differentiation whereas formants F3 and F4 are speaker-specific [24].

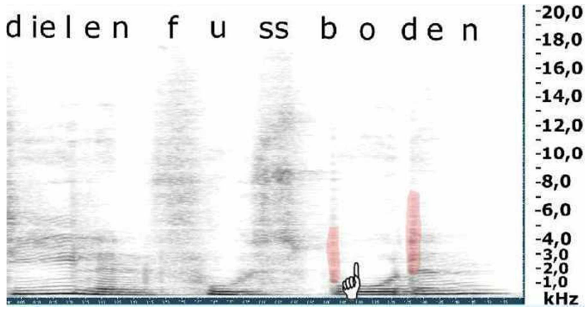

Figure 2. *The German word, Dielenfußboden" as a spectrogram.*

The x-axis represents the length of articulation in ms. The y-axis gives the sound pitch in kHz. Formant transitions at /ie/ are clearly visible as horizontal shading [25].

The base frequencies for consonant formants lie at the top of the range (cf Figure 2). Consonant differentiation therefore calls for good hearing and the ability to perceive high pitches [24]. Phone discrimination problems are supposed to be caused by shortcomings in the ability to process formant transitions [26].

In addition to pitch differences, phone discrimination is also affected by processing speed, as different phones are articulated at differing lengths (c f Figure 2). It is essential to bear this in mind, given the importance that attach to phonological loop precision for auditory working memory capacity [27]. The difference in phonation length between the German plosives [g] and [k], between [d] and [t], and between [b] and [p], for example, is a mere 20 milliseconds. Problems in registering phonation length are due to slow cortical acoustic signal processing [28].

3.2. Prosody: Music in Language

Musical parameters like tempo, rhythm and pitch work alongside body language in helping to express the rhythmic structure of language and the emotional content of a spoken message. A phonological word comprises both strongly and weakly accentuated syllables and the prosodic structure of a language is closely associated with its grammatical structure, giving each language its typical melody [29, 30]. Individual elements of language and music are bound together in a system of rules – the syntax – in hierarchically structured sequences [17, 31].

3.3. Processing Language and Music

Neuroscientific research findings indicate the existence of a music-language network in the brain. Language and music are processed in the same – or overlapping – regions of the brain [17, 20]. A lot of children with SLI have problems in dissecting information contained in the prosodic parameters, e.g. the switch between stress and unstressed, or the emotional content of a message [29, 32].

There is a link between speech comprehension disorders and the non-recognition of rule violations in relation to pitch and rhythm in well-known children's songs. This has been attributed to the inability to automatise the processing of speech signals [17, 20, 33, 34]. Children with a specific language development disorder find it difficult to recognise syntactical irregularities in both speech and music [17, 20]. These children have limited capacity for sequences of notes and a restricted phonological working memory [20, 35].

3.4. Auditory Training with Music

There are numerous studies that confirm the favourable effect that music-making has on the development of speech stimuli [34, 36]. The wide range of synaptic associations and precision needed for making music and for the rapid processing of music are all available for language-related processing [34]. It seems therefore entirely logical to utilize the common ground between music and language to use music-based auditory training to correct deficits in language perception. This is not universally accepted though [15, 16].

The evaluation study presented here is based on the author's positive practical experience with auditory training. The music used is a selection of works by Mozart, Bach and Vivaldi, played on bowed or plucked instruments and on woodwind. The music is processed by a converter, whereby frequencies of below 1000 Hz are removed, and the high frequencies filtered to make them higher still. This is done alternately left and right (i.e. laterally, Figure 3). There are a series of stimulation levels: the faster the running time, and the higher the filtration and application levels, the stronger the stimulus: level 1 is lowest; level 6 highest [25, 37-39].

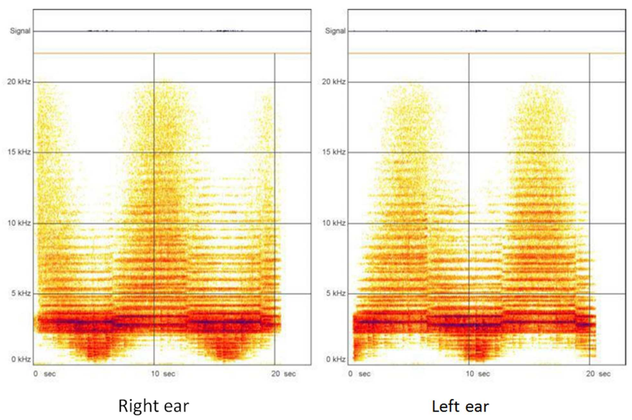

Figure 3. *Filtered music.*

Filtered music: High and medium (> 2000 Hz) frequencies are compressed with intervals and shifted left-right. Low (< 1000 Hz) frequencies are reduced in the counter-phase, or eliminated entirely. The effect is to greatly reduce the orchestral volume [25].

4. Method

4.1. Research Design

The research used a pre post design, with one experimental group and two control groups. The experimental group applied auditory training; the other two were identical in terms of age, sex, language ability and phonological working memory: one was the wait list control group, the other a special-attention group. The children in all three groups were put through the same battery of tests; the observation period was around 15 weeks. In all cases, the children's auditory working memory was tested before and after the observation period.

4.2. Selection of Test Subjects

Data were collected from March 2010 to June 2013 in Northern Germany. Preschool children of between 4 and 6 years of age with German as their native language from nine establishments were selected on the strength of their teachers' assessment of their poor ability to: pay attention; understand what they were being told; make themselves understood in speech. Any one of these attributes sufficed. Exclusion criteria were: mental impairment; trauma; dependence on hearing aids; acute liability to catch cold; consistent use of the plosive [t] instead of [k] and of [d] instead of [g]. A further condition was that children in the experimental group should not be undergoing speech therapy.

The children were tested for receptive language performance, the underlying assumption being that there is a correlation between language comprehension and phonological working memory. Comprehension testing used the TROG-D grammar protocol [40]. Any children with a low level of receptive performance were subjected to the Heidelberg auditory screening procedure under the HASE protocol [41].

In light of the view that the precision of the phonological loop component plays a part in working memory storage capacity [27], a number of tests on the AUDIVA® test CD were used to check for auditory function [42], Two of the tested elements were phone discrimination ability and high-pitch comprehension, given the connection relevance of the formants for sound discrimination in the high-pitch range [24]. Subjects were required to repeat single-syllable nonwords and, for high-pitch comprehension, to reconstruct German infinitives with an initial syllable where the frequencies below 4000 Hz, 3000 Hz or 2000 Hz had been removed. Because conditions were not right in some of the test venues, only some of the children were tested for sound discrimination capability and high-pitch perception.

92 children were finally selected as test subjects, all of whom had a phonological working memory in the risk range. Some of the children were observed in several phases over an extended period, with the result that the data available for analysis emanated from 116 subjects. The average age at pre-testing was 59 months (SD = 7.2 months).

4.3. Subject Groups

4.3.1. Control Groups

The children in the wait list control group underwent normal teaching between pre- and post-testing. Members of the special-attention group received around 12 weeks non-specific attention or special-needs provision of comparable intensity.

4.3.2. Auditory Training Group

The children in this group received auditory training using technically altered music. This involved use of an electronic device incorporating a CD player and headphones. The training plan was standard to all; all the children used the same semi-open headphones. Volume and sequence of the music were standard for all devices.

The plan was to conduct the training without interruption wherever possible for 12 calendar weeks, with breaks for public holidays and other special occasions. The idea was that the children in the training group should listen in small groups to technically altered music through headphones for 3 x 30 minutes each week, always in the presence of an adult. The trigger volume began at level 2 and went up a level after six sessions each, such that in the final two weeks, the stimulation level was at the maximum of 6. While they were listening to the music, the children were allowed to occupy themselves quietly.

5. Results

The underlying hypothesis was that the training undergone by the experimental group would lead to a significant improvement in children's 1) phonological working memory capacity; 2) high-pitch comprehension; 3) phone discrimination faculty.

The differences in findings between pre- and post-testing among the training group were compared with those of the two control groups, using a t-test for unbiased sampling. The level of significance was set at =.05. A pre- and post-testing comparison of the mean values of the group findings with the standard deviations is set out in Figures 4-7. The training group is labelled HG, the wait list group WG and the special-attention group PFG.

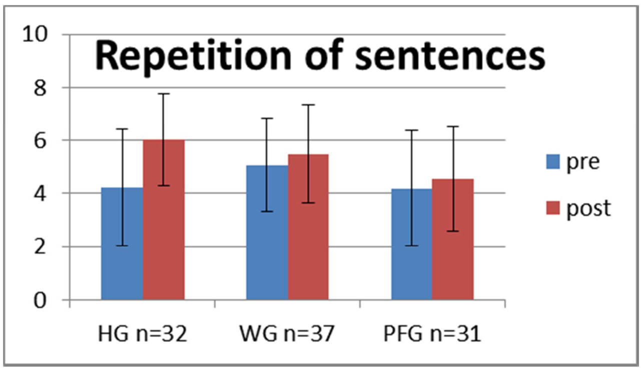

Figure 4. *Pre-post comparison of means with standard deviation: Repetition of sentences.*

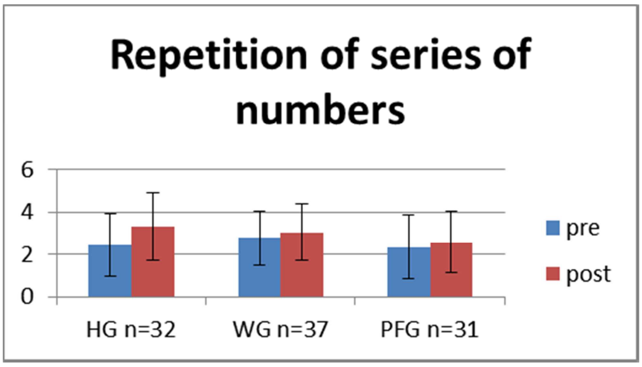

Figure 5. *Pre-post comparison of means with standard deviation: Repetition of series of numbers.*

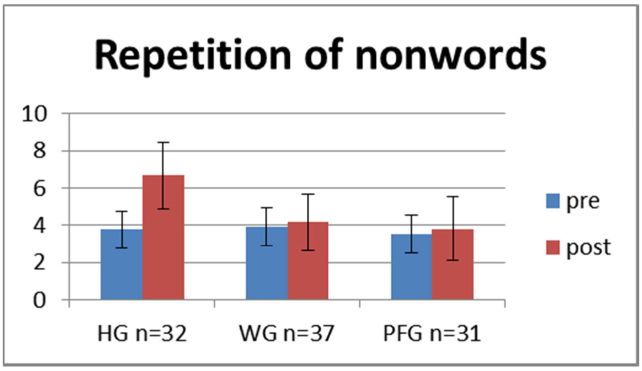

Figure 6. *Pre-post comparison of means with standard deviation: Repetition of nonwords.*

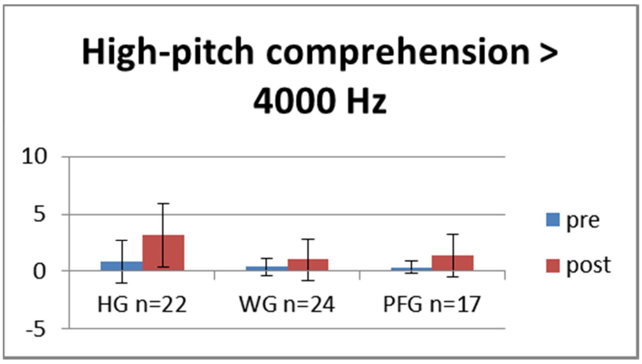

Figure 7. *Pre-post comparison of means with standard deviation: High-pitch comprehension > 4000 Hz.*

The findings bring out clearly that the effect of auditory training is greater than the progress made by the children pursuing normal schooling over the same period. It also exceeds the improvement attained with the special-attention group. The improvement in all areas achieved by the training group was significant ($p < .05$) compared with the wait list group. Compared with the special-attention group, all the results returned by the training group in the HASE tests were significant ($p < .05$) in terms of auditive working memory and in high-pitch comprehension > 4000 Hz. While improvements in high-pitch comprehension > 3000 Hz and > 2000 Hz and sound discrimination were more marked than in the special-attention group, they fell below the significance threshold. Figures 4-7 concern pre-post comparisons which were significant vis-à-vis the special-attention group.

For 16 of the children who did the auditory training, the post testing was carried out 5-6 weeks after the end of the training phase and some 20 weeks after the pre testing. There was no significant difference in the findings compared with the 52 children who were tested immediately after the training phase. In other words, the training continued to have an effect for some weeks at least after the training was completed.

There was no post-testing of grammar comprehension because the ítem "*Repetition of sentences* "requires correct reproduction, i.e. semantical and grammatical processing of the sentence. That automatically includes speech comprehension. [41].

6. Discussion and Conclusion

The importance working memory for a child's learning and development [1] and the fact that the of the capacity of PSTM it is held to be non-trainable [6] add particular weight to the findings of this study. There are a wide range of preschool learning programmes, all of them aimed at preventing learning problems at school. A number of the children in the special-attention groups took part in these. Even so, the positive effects of auditory training were much higher in all test areas – significantly higher in the case of phonological working memory and of high-pitch comprehension > 4000 Hz ($p <.05$).

There are other aspects, though, which raise certain doubts. All the children who took the speech comprehension test were classed as at-risk, thus confirming the views that comprehension problems are frequently missed [8, 12, 13]. Children in the wait list control and auditory training groups received no special attention, in most cases due to lack of facilities and/or money. Only a small fraction of the subjects was receiving speech therapy or special preschool measures. The work done with the special-attention group was either set up specially for this research or formed part of the teaching programme in an elite institution with particularly keen teachers.

This research has generated the evidence-based and scientifically founded proof demanded by Lauer [27], of how effective non-linguistic, music-based auditory training can be.

The second unit of the functional units of the brains in Lurija´s model was stimulated [21]. The findings of this study also confirmed two studies both of which concluded that music can be a fruitful basis for auditory training [43, 44]. The auditory stimulation enabled the children in the experimental group to improve their phonological working memory capacity significantly ($p <.05$) as against the children in the two control groups within a relatively short space of time. The improvements in high-frequency comprehension and discrimination were likewise significant ($p <.05$) compared with the wait list group, and the differences compared with the special-attention group in the high-frequency range < 4000 Hz were also significant. This shows that auditory training in the high frequency range is very effective. Although it was not possible to conduct any follow-up testing, the findings with the 16 children who were tested several weeks after the completion of training would seem to indicate that the positive effect can be sustained. Music-based auditory training is not just effective: it is also efficient, in that up to ten children can be catered for at the same time with the help of just one adult requiring no special training. The children simply heard the music, which they liked, in the background as they got on with other, quiet occupations. No effort whatever was required of them. It is therefore a useful and economically attractive complement to existing measures like one-to-one speech therapy or preschool special activities. It can be dispensed in a group situation and it is quick-acting.

There are a number of more anecdotal observations and data which emerged from the research, but which were not taken formally into account. Parents and teachers alike reported that the children undergoing the training were quieter and more attentive, and that there were other positive changes which escaped formal identification. This accords with the findings of Alloway & Alloway concerning the effect that working memory has on children's behaviour [1]. Some reacted more calmly to the general hubbub of preschool classroom activities, i.e. they became better at filtering out unwanted noise.

This study was performed with relatively small groups of subjects and they were tested with behavioural methods. Not all positive effects that were observed like filtering out unwanted noise or other behavioural aspects could be examined in this study. Further research with neuroscientific methods and graphic measures on the effects of different music-based auditory training methods available might bring out the function and efficiency of them more clearly.

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