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Is it possible to improve hearing by listening training?

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Summary
Different listening training methods exist, which are based on the assumption that people can be trained to process incoming sound more effectively. It is often distinguished between the terms hearing (=passive reception of sound) and listening (=active process of tuning in to those sounds we wish to receive). Listening training methods claim to benefit a wide variety of people, e.g. people having learning disabilities, developmental delay or concentration problems. Sound therapists report about improved hearing/ listening curves following listening training programs. No independent research study has confirmed these results using standardized hearing test measures. Dr. Alfred Tomatis, a French ear nose throat doctor, developed the Tomatis listening training in the 1950s. The principles of the Tomatis method are described. A literature review has been conducted to investigate, whether the Tomatis method is based on assumptions, which scientifically hold. The results of the literature study are discussed. A research study is proposed, in which the effects of the Tomatis method on hearing will be investigated using both conventional hearing threshold measurements and objective measures such as otoacoustic emissions.

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1. Introduction

Sound stimulation, sound treatment, sound therapy, sound training, listening training, auditory training and music training: all these terms describe therapy forms in which people are stimulated by sound in a passive manner. Some therapy forms also have an active part, but the therapy mainly consists of a passive stimulation with either sounds or music. This is in contrast to music therapy, in which clients mostly work with music in an active manner. It is well-known that music or sounds can have positive psychological effects on people. Widex has developed a relaxation tone program for their hearing aids, called Zen, which plays random and harmonic tones in order to manage stress caused by tinnitus. But can sound stimulation also have physiological and/ or neurological effects and train the ear to perform better? Sound stimulation programs claim to be able to "restore" hearing or to "re-educate" listening and are based on the assumption that people can be trained to process incoming sound more effectively. Listening is in contrast to hearing defined as the active process of tuning in to sounds we wish to receive and screening out sounds we do not wish to receive. Although a person can hear, he/ she might not always be a good listener. Listening training uses sound stimulation to exercise the ear's listening function, a kind of "earobics".

Dr. Alfred A. Tomatis, a French ear, nose and throat doctor, developed a listening training method called Tomatis method, Tomatis therapy or Audio-Psycho-Phonology (APP). The Tomatis method claims to benefit a wide variety of people having problems that have listening as their foundational skill ([1]):

- *Neuro-developmental maturation (of speech, language, motor skills, etc.)*
- *Communication skills (language-based, social, and business applications)*
- *School learning skills and abilities*
- *Attention and the organization of behavior*
- *Social relationships and self-esteem*
- *Foreign language learning*
- *Musical applications for singers and musicians*
- *Relaxation*
- *Neurological rehabilitation for head injuries, strokes, etc.*

Listening training methods are often criticized because there is not sufficient scientific evidence for their efficiency. The methods have been developed by experience rather than on the basis of scientific validation. Most studies that exist on the efficiency of listening training methods originate from people working within that field, and results are often presented as case studies [2, 3, 4].

2. The Tomatis method

Tomatis developed **Three Tomatis laws**, the first law was discovered when he compared audiograms and spectrographs of two patient groups: ammunition factory workers with hearing loss and professional singers, who had difficulty producing sounds they once had easily produced ([5]).

1. The voice can only produce what the ear can hear - The voice only contains the harmonics that the ear can hear. (Tomatis effect, confirmed at the Sorbonne in 1957)
2. If the sounds are restored to the ear, they will be immediately restored to the voice.
3. With sufficient conditioning of one's ear to one's own voice heard with good quality, the changes can be maintained and strengthened.

Tomatis designed an audio device called the Electronic Ear (EE), which processes the sound in order to re-educate the ear to work in its optimum way.

The Electronic Ear (EE) The electronic ear (EE) delivers sound through special headphones with both bone and air conduction. The most important features of the EE are described by [6]:

1. *Tomatis built into the EE a set of filters to regulate sound so that the information is altered or modified to focus evenly on the specific frequency band range of a good functioning ear in order to suppress distortion. Besides settings to extend the range of listening and speech as wide as possible, the filters can be set to improve reception for a particular language and to develop a musical ear, which he considered to be an ideal listening ear.*
2. *The electronic gating mechanism enables the ear to attune itself automatically and spontaneously for listening. Stimulation of the middle ear is achieved by the alternating passage of sound from one channel* [boosting low frequencies], *which is set to relax the muscles, to another channel* [boosting high frequencies], *set to tense or focus the muscles. Repetition of the gating action over time conditions the ear to operate more efficiently to perceive and analyze sound properly.*
3. *The EE provides a control to vary the balance of sound between the right and left ears. The most direct route to the speech center in the left side of the brain is through a dominant right ear. Sound intensity fed via earphones to the left ear is progressively reduced so as to prepare the right ear to become the lead ear for listening and audio-vocal self-monitoring.*
4. *The timing delay of sound reception between the bone and air conduction can be changed to slow down the processing of information internally and to awaken the individual to attend to incoming information. The delay is gradually changed to support a more rapid response to incoming information.*

Tomatis treatment
Before the Tomatis treatment an anamnesis is performed to find out why the client consulted a Tomatis center. Various tests are performed including a listening test for air- and bone conduction, a laterality test and a selectivity test. Based on the results, the listening program is designed individually. During the treatment individuals typically listen from one to two-and-one-half hours daily to music (Mozart and Gregorian chants) and, if possible, recordings of the mother's voice. The sounds are processed through the EE. While listening, individuals participate in creative activities such as drawing, painting, putting puzzles together or relaxing. The listening program has both passive and active phases. During the active phase, the individual speaks into a microphone as his or her voice is played back to his/ her own ear through the EE. A minimal program typically occurs within two or three periods covering at least 60 hours. Three- to six-week breaks for integration of changes separate the periods.

3. Literature study

Tomatis designed the EE in accordance with his theories of how the ear works. The method is based on many assumptions on how the ear works and how it can be "trained". These assumptions have not all been scientifically proven. A literature study has been performed by the author in order to investigate, for which features of the EE scientific support exists.

The Mozart effect The main part of the Tomatis method consists of passively listening to Mozart music through the Electronic Ear. Since Campbell has published his book "The Mozart Effect" ([7]) a lot of debate is going on about whether the Mozart Effect exists. By the public the "Mozart effect" has been oversimplified and has turned out to become "music makes you smarter". Originally, [8] performed an experiment in which students were given spatial reasoning tasks after listening to 10 minutes of (1) Mozart sonata for two pianos in D major, KV448), (2) a relaxation tape or (3) silence. The results of the experiments were that subjects performed better on the spatial reasoning tests after listening to Mozart than after listening to either the relaxation tape or silence. The authors pointed out that the enhancing effect of the music was temporal and did not extend beyond the 10-15 minute period during which subjects were engaged in the spatial task. The authors could replicate their findings in an additional study ([9]): In a paper folding and cutting task subjects, who had previously listened to the same piece of Mozart music as in [8], performed significantly better than subjects who had listened to either mixed stimuli or silence. The authors suggested different explanations for this effect: *(1) Listening to music helps 'organize' the cortical firing patterns so that they do not wash out for other pattern development functions, in particular, the right hemisphere processes of spatial-temporal task performance. (2) Music acts as an 'exercise' for exciting and priming the common repertoire and sequenitial flow of the cortical firing patterns responsible for higher brain functions.* [10] measured electroencephalogram (EEG) recordings while subjects were listening to the Mozart sonata for two pianos in D major, KV448 and while subjects performed a paper folding and cutting task. The authors reported that *the presence of right frontal and left temporal-parietal coherent activity induced by listening to Mozart which carried over into the spatial-temporal tasks in three of our seven subjects. This carry-over effect was compared to EEG coherence analysis of spatial-temporal-tasks after listening to text. [] The observed long-lasting coherent EEG pattern might be evidence for structured sequences in cortical dynamics which extend over minutes.*

Many other researchers have tried to reproduce the "Mozart effect", but no study could replicate the same results that were obtained by [8]. [11] published a meta-analysis of 16 studies and concluded that there may be a small temporary effect, but that this effect probably arises from "enjoyment arousal" induced by the music compared to sitting in silence. [12] examined whether the Mozart effect is a consequence of arousal and mood by presenting three conditions (Mozart sonata for two pianos in D major, KV448, Albinoni's Adagio in G Minor for Organ and Strings, and Silence) prior to a paper folding and cutting task. The Profile of Mood States, which assesses arousal level and mood of the subjects, was measured. The authors concluded that *their findings provide compelling evidence that the Mozart effect is an artifact of arousal and mood.*

Lateralization - right ear dominance Lateralization refers to the development of lateral dominance (i.e. right or left eye, ear, hand or leg) and development of specialised centres and functions in the left and right brain hemispheres. According to Tomatis it is advantageous to have a leading right ear, from which the crossed nerve fibres are directly connected to the left hemisphere of the brain, in which speech is processed. A leading left ear results in a slower processing of speech, because the signals are first transmitted to the right hemisphere and afterwards, with a delay, to the left hemisphere. In the Tomatis method the lateralisation is determined by observing the test subject while speaking in his/ her mother tongue. The leading ear is typically on the side on which the face is moving most actively. By letting the test subject talk into a microphone and giving the subject his/ her own voice as feedback via headphones, the volume contralateral to the leading ear is increased until the movements of the face are symmetric. In this way the degree of lateralisation is determined (e.g. from 5 to 30 dB). Subjects with leading left ears receive a treatment in which they are exposed to higher sound levels on the right ear. According to Tomatis, it is possible to switch laterality. A switch of laterality leads according to Tomatis to a faster processing of speech and to a less monotone voice.

It is widely accepted that speech is processed in the left hemisphere in the majority of adults ([13, 14]). [15] pioneered the dichotic listening procedure to asess speech lateralization. She showed a close relationship between ear superiority and speech dominance. In a study of neurological patients of known speech lateralization, she found that left-hemispheric dominant subjects were more accurate at identifying verbal material presented to the right ear, while right-hemispheric dominant subjects were more accurate at identifying verbal material presented to the left ear. Kimura's findings indicated that this effect was independent of handedness. The results are consistent with earlier suggestions that the crossed auditory pathways are stronger than the uncrossed, and that the dominant temporal lobe is more important than the non-dominant in the perception of spoken material.

There are many indications of lateralization of the human auditory system at other stages than at the hemispheric level. [16] provides an overview: *Auditory thresholds between 2000 and 6000Hz were found to be significantly lower in the right than in the left ear in a study involving 538 young boys [17]. In the auditory brainstem, during sound perception, the mean amplitude of wave III is larger when the right than the left ear is stimulated [18]. Moreover, it appears that the left ear is more susceptible to noise damage; the average temporary threshold shift after binaural exposure to loud noise being higher [19]. The left ear is also more vulnerable to auditory pathology, such as tinnitus [20, 21] or hearing loss.* The medial efferent system (assessed by the measurement of contralateral attenuation of evoked otoacoustic emissions) has been found to be more effective in the right than left ear in right-handers [22]. The authors propose that *the lateralization of the efferent system may already, at a peripheral level, favour language treatment by the right ear, specifically linked to the left hemisphere.*

In the literature, the difference between left and right ear sensitivity has been explained by left ears receiving a greater exposure to intense sound than right ears. However, the right ear advantage in sensitivity also exists in children and in adults having limited exposure to extense sounds (see [23] for a literature review), therefore the author suggests that the ear asymmetry may be a manifestation of a fundamental difference in the bilateral organization of the human auditory system. [24] demonstrated right-ear speech lateralization for boys and girls as early as age four, suggesting that left cerebral dominance for speech is established by the age of four, and eventually earlier. [13] investigated genetic factors in speech lateralization and suggests that dichotic listening laterality, and possibly speech lateralization, are more influenced by environmental than by genetic factors. [25] found that children with hearing loss on the left ear do not have learning difficulties, whereas 50% of children with hearing loss on the right ear had difficulties. Research performed by [26] showed, that more than 80% of good readers hear best on their right ear (hearing was tested both with conventional audiometry, speech audiometry and dichotic listening test). In the literature it is suggested that speech processing is more efficient through the right ear for subjects with speech represented in the left hemisphere. No scientific evidence could be found in the literature for whether it is possible for subjects to switch laterality, whether a relation exists between ear dominance and the processing time for speech and whether a relation exists between ear dominance and the voice characteristics (monotone vs non-monotone voice).

The voice can only contain what the ear can hear Tomatis suggested that the two organs, ear and larynx, are part of the same neurological loop. Therefore, changes in the ear will immediately affect the voice, and vice versa. In the Tomatis method subjects are exposed to filtered sounds (passive phase). In the active phase, subjects speak/ sing while receiving auditory feedback of the (modified) voice. It is well-known that auditory feedback has an influence on speech. Speech intensity is increased in noisy environments [27]. Temporally delayed feedback induces disfluent speech [28]. Auditory feedback including pitch changes or formant shifts alters the vocal output in the direction opposite to the shift (e.g. [29] and [30], respectively). [31] investigated the neural subtrates underlying this auditory feedback control of speech by using a combination of functional magnetic resonance imaging (fMRI) and computational modeling. Two conditions were used while subjects spoke monosyllabic words: (1) normal auditory feedback of their speech and (2) auditory feedback in which the first formant frequency of their speech was unexpectedly shifted in real time. The results demonstrated *clear evidence of feedback-based correction of segmental vocal output. Imaging data indicated that, in the absence of feedback error, articulator control was left-lateralized in the frontal cortex. When auditory error was introduced via the F1* [first formant] *shift, right hemisphere frontal regions, particularly ventral precentral and inferior frontal cortex, were recruited to participate in corrective articulator movements.* In his third law Tomatis states that with sufficient conditioning of one's ear to one's own voice heard with good quality/ modifications, the changes can be maintained and strengthened. No literature has been found on long-term effects of auditory feedback. One study has been found in which voice characteristics have been monitored before and after the Tomatis training. [32] measured long-term average spectra of voiced and whispered speech of three subjects who had undergone the Tomatis audiovocal training (active phase). He found *(1) Decrease in energy in the 50- to 200-Hz zone; (2) increase in energy in the 800- to 1200-Hz zone; (3) different individual overall energy shifts; (4) larger and wider formantic peaks in the long-term average spectra; (5) increase in global energy; (6) greater pitch and power variability; and (7) increase in average pitch.* [33] compared measured spontaneous otoacoustic emissions (SOAEs) from the ear with a frequency analysis of the voice recording and found 100% correlation between the stressed frequencies of the SOAEs and voice. She proposed an addendum to the three Tomatis laws, stating that *the ear emits the same stressed frequencies that are emitted by the voice.*

Optimal processing of sound - role of middle ear Tomatis gating separates music into 2 channels, alternating (or "gating") them, with one channel boosting high frequencies and the other channel boosting low frequencies as the music volume increases and decreases. Tomatis states that *this causes the muscles in the middle ear to continuously tighten and relax, a process that strengthens them. As the muscles become stronger so does our ability for focused listening and paying attention.* No studies have been found that have investigated, whether it is possible to strengthen the middle ear muscles.

Delay between bone- and air conduction In the Tomatis method the sound is presented both via air- and via bone conduction (via a vibrator placed on the top of the head). Because of the difference in speed of sound of the two mediums the travelling time of the bone conducted sound to the brain is assumed to be faster than the air-conducted sound. According to Tomatis, the bone-conducted sound serves in this way as a wakeup call to prepare the brain for incoming sound. The delay between bone- and air-conducted sound is varied. A long delay trains this prinicipal of wakeup call, a gradual decrease of delay is supposed to support a more rapid response to incoming information. No studies have been found in the literature which support these ideas. [34] reports about his own experiences that he himself experienced improvement of auditory processing times after the Tomatis therapy. He also talked to psychologists and behavioural therapists who experienced that sound therapy resulted in a reduction of auditory processing time of

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children leading to a significant improvement in the children's comprehension.

Interpretation of listening curves According to Tomatis there is an interaction between listening, the voice and posture. In the Tomatis method the "listening curves" are obtained, which are air- and bone-conduction thresholds using a descending method without repetitions. A conventional audiometer is used, that is calibrated according to Tomatis. The listening curves are interpreted according to the shape of the air-conduction curves, the relation between air- and bone conduction, the similarity between left and right ear. According to Tomatis "a good listening posture is related to a straight back". Several studies have demonstrated that the auditory system is sensitive to changes in posture, presumably through changes in intracranial pressupre that in turn alters the intracochlear pressure, which affects the stiffness of the middle-ear system. [35] found significant changes between upright and tilted positions for DPOAE magnitude at frequencies between 500 and 2000Hz, and DPOAE angle changes were significant at all measured frequencies (500-4000Hz). "A listening curve with a steep slope at high frequencies is interpreted as a depression." [36] showed that pure-tone auditory thresholds were decreased in depressed people with post-traumatic stress disorder.

The Tomatis method provides stimulation, which promotes nerve growth Tomatis developed a method specifically to stimulate the interconnections between the ear and the nervous system [6]. Theories behind this could be that the myelination of the auditory pathways, which improves the speed of processing of the auditory signals [37], is stimulated. It is now known that even in adults, the brain continues to change and develop throughout life via sensory stimulation from one's experienes [38], also known as brain plasticity.

Effects of sound on hearing In general, research studies have shown that sounds can have both harming and protecting effects on hearing. Hearing can be irreversably damaged by exposure to excessive sounds, leading to noise-induced hearing loss. Depending on the level and duration of a sound, it may cause permanent or temporary hearing losses. A moderate-level sound stimulation presented prior to a traumatic sound has shown to have a protective effect hearing of animals (e.g. [39, 40]). It is not known, in which part of the hearing system this ameliorative effect of sound is induced, the central auditory or the peripheral system.

4. Research strategy

As it has been described in the previous sections, the Tomatis method works with various parameters. A systematic investigation would test the effect of a single parameter at the time, which would be very time consuming. There are some indications that the Tomatis therapy might have a positive effect on hearing, though this is not the primary goal of the Tomatis method. It is the purpose of the proposed study to investigate, whether the Tomatis method has a positive effect on the hearing function. It is not known, which part of the hearing (middle ear, inner ear or neurological pathways) is affected by sound stimulation. A systematic investigation of different types of hearing tests before and after sound stimulation could provide more information on, whether the sound stimulation affects the auditory system, and if yes, which areas of auditory processing are most affected. The hearing assessment for such an investigation will include subjective tests (which might be influenced by training effects etc.) such as e.g. absolute threshold with air- and bone-conducted sound, masked thresholds, speech intelligibility tests and dichotic listening tests which test for whether the right or left ear is dominant. Several objective hearing tests, which do not require the active participation of the tested person, exist. Otoacoustic emissions are widely used for the hearing screening of newborns and provide information about the status of the inner ear, in particular the state of the outer hair cells [41]. Amplification/ improvement of otoacoustic emissions in 50-60 % of subjects after sound stimulation with the Tomatis method has been reported [42], but has not been published scientifically in peer-reviewed journals.

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