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Comparison of Effects of Auditory and Music Training of Blind or Visually Impaired Young People on Performance in Selected Auditory Tasks

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Performance of blind/visually impaired children and teenagers before and after the auditory training and the music training in some auditory tasks (pitch discrimination, pitch–timbre categorization, pitch memory, lateralization of a stationary sound of a drum, lateralization of one or two moving motor vehicles) is compared. In the auditory training, the subjects were actively involved, i.e. they had to answer questions related to presented sound material. The music training was based on passive listening to sounds presented according to the Tomatis method. The training (auditory or music) effectiveness was measured as a difference between results of a pre- and post-training verification test in which the subjects were asked to perform the auditory tasks mentioned at the beginning. The persons who took part in the study were divided into two age groups: 7–12 year olds and 13–19 year olds. According to the results, the auditory training was beneficial for blind or visually impaired teenagers, especially in respect of lateralization tasks. For small children the auditory training was not as effective as for adolescents. However, it has been shown that the music training was generally beneficial for them, although none of the verification tasks was privileged.

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1. Introduction

People who are blind or visually impaired rely on hearing and touch to compensate for their lack of vision. It is well known that auditory skills are crucial for them in the development of spatial orientation, distance assessment, sound source identification and localization, obstacle detection and avoidance [1], perception of landmarks, and personal interactions [2]. Auditory skills appropriate for safe, effective, and independent navigation at home, work, school, public institutions, or in city streets require time and effort from a blind person. The orientation and mobility skills in blind young persons are low and require extensive and appropriate training. The training is necessary to teach them to maximize the use of hearing, the second (after sight) most important human sense, in safe and independent navigation in an urban environment. Small changes in acoustic parameters of environmental sounds convey information about changes in the surrounding environment. Concentration of attention and correct interpretation of the sound changes may help blind or visually impaired young persons in active participation in a community life provided they are taught how to retrieve information from the sounds.

Superior auditory skills of blind individuals have been often reported in neuropsychological papers. Early blind adults perform better in frequency discrimination [3–4], pitch and timbre categorization [5], sound localization [6–8], or speech perception [9]. In the blind or visually impaired children, superior performance in auditory tasks, similar to the performance of blind adults, is not confirmed [10–11].

There are numerous papers reporting functional and structural changes in the auditory system resulting from an active music training of children and adults across the life span [12]. They show that the music training improves the auditory skills that are not exclusively related to people who show aptitude towards music (e.g. auditory processing, auditory attention, or tracking regularities in an environment) [13–14]. There are only a few reports on the acoustic and music training for learning and rehabilitation of people with visual disabilities. They come from neuroscience laboratories and are related to assistive technologies for the blinds [15–16] or acoustic virtual reality [2]. However, it is now widely accepted that music training can be a strong multimodal stimulant of brain plasticity [17–18]. Different stimuli used in acoustic and music training are reported: artificial sounds like pure tones [16], high-frequency broadband signals [15], overlapping bands of noise with dynamic interaural level differences, interaural time differences, and Doppler shift [8]; further, music sounds like consonant or dissonant tone pairs, music intervals, and passages [14] as well as natural or virtual environmental sounds. Various duration times of auditory training were reported. There were twelve 1-hour-long sessions [16] and 4 sessions lasting 2 hours each [15]. Music training usually lasted months or years [13].

Analyzing the above-described results concerning perceptual skills of the adult blinds and significantly worse skills of visually handicapped or blind children and teenagers together with description and results of

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auditory and music training, we decided to compare the effect of our own acoustic training (AT) and a popular music training (MT) on selected auditory skills of young visually impaired subjects. To our best knowledge, the effect of auditory and music training on perceptual skills in blind/visually impaired children and teenagers has not been studied yet.

The aim of this paper is to compare effectiveness of the auditory training (AT) and the music training (MT) offered to the blind or visually impaired children and teenagers. A measure of the effectiveness is the difference in results of the verification test the participants were asked to take before and after training.

2. Auditory and music training

In our previous papers we have presented a detailed concept of and physical parameters of signals used in our auditory or acoustic training (AT) [19], based on artificial sounds [19–21] and its effects on auditory competences of children and adolescents with visual problems [21]. Such training may also be beneficial for the orientation and mobility training of visually handicapped individuals [22]. As our AT has been well-described in our previous papers, here we recall only some basic information. The training comprised psychoacoustic and lateralization tasks, like pitch discrimination of tones, noise bands, and frequency modulated signals; pitch memory; loudness discrimination of tones, noise bands, and amplitude modulated signals; lateralization of tones and noise signals; timbre discrimination of harmonic signals; simultaneous categorization of pitch and timbre of harmonic signals and sounds of musical instruments, and signal-in-noise detection. Sounds were presented monaurally or binaurally (depending of a task) on a comfortable level of 65 dB SPL. The method of constant stimuli was used. The transformed up-down method with the adaptive Levitt procedure, a popular method used in psychoacoustic experiments, was not used as excessively time-consuming and therefore not suitable for small children who are not able to concentrate for a long time. The task of the subject was to answer a question after each presented piece of acoustic material. Each subject took part in twenty training sessions lasting 40 minutes each [21]. The auditory training took 4–5 weeks, and its duration did not differ significantly from training duration times reported previously [15–16]. The signals, the manner of their presentation, and duration were the same or very similar to those reported by other authors [3–8, 14–16].

As the Tomatis method and equipment is available to pupils from schools for the blind and visually handicapped children in Poland, we have decided to use them as a setup for music training. The music training in the form proposed by Alfred Tomatis is often criticized by the scientific community because there is no sufficient evidence for its scientific base. It is promoted only by its authors [23] and active users, e.g. the Institute of Physiology and Pathology of Hearing, Warsaw [24]. A part of the Tomatis method used in our investigation comprises passive listening to Mozart music modified by a set of filters (called the electronic ear) and presented through headphones with air and bone conduction. Stimulation of the middle ear is achieved by alternating presentation of music signals with low and high frequencies amplified. The method proposed by Tomatis is based on many of his own assumptions on how the ear works and how it can be "trained". Not all of these assumptions have been scientifically verified and we will not quote them in their original form but present briefly a critical literature overview of some of them after Andersen [25–26]:

– The Mozart effect. According to some reports [27], subjects performed better on spatial reasoning tests and in paper folding and cutting tasks after previous listening to Mozart music than after listening to relaxation sounds or silence. In fact, no study has reproduced such effect and it is beyond any doubt that the Mozart effect is an artefact of arousal and mood and has nothing to do with making subjects smarter [26, 28].

– Interpretation of listening curves. They are air- and bone conductive thresholds obtained using a conventional audiometer calibrated according to the method. Interpretation given by Tomatis is bizarre and has no common points with the present-day psychoacoustic knowledge.

– Strengthening of middle ear muscles. According to the method, alternating presentation of sounds amplified in low and high frequencies via a bone headphone makes middle ear muscles stronger and improves the ability to maintain acoustic attention and focus on listening. No study has reported the possibility of the muscles strengthening [26] and its influence on auditory competences.

– Advantage of the right ear dominance. The method states that it is advantageous to have the leading right ear because it reduces time for speech processing due to shortest neural path between the right ear and the left brain hemisphere responsible for speech processing. There are no reports showing the effect of ear dominance on the processing time for speech or whether switching of human laterality is possible [26].

Despite the above-presented critical comments about the Tomatis method and knowing that there are many myths or "author's secrets" related to the details of signal processing [28], we decided to use its sounds and equipment in the music training (MT) for blind/visually handicapped children and teenagers, assuming, on the basis of reports of other authors [13–16], that any kind of music training may be potentially beneficial for our subjects. We would like to stress that according to its classic assumptions, the Tomatis method is not addressed to the blind or individuals with vision problems. It is designed mainly for children and youth with educational problems, behavioral difficulties, and language disorders. There are no reports describing the effect of the Tomatis training on perceptual skills of such subjects. For each subject, twenty training sessions were performed, each lasting 40–50 minutes, similarly to the duration of the auditory training. No action was demanded from subjects. The music training lasted for 4–5 weeks, similarly to AT. Sounds were presented on comfortable listening level. Both training types were carried out with young persons because they are a promising and potentially the most beneficiary group of the blind [14, 21].

To compare the effect of both training methods, the training verification test was prepared [19]. The verification test was composed of 6 tasks checking the pitch discrimination (task 1), pitch and timbre categorization (task 2), pitch memory (task 3), lateralization of a stationary sound source (task 4), lateralization of a moving sound source (task 5), and lateralization of two moving sound sources (task 6). Tasks 1–3 were the most difficult variants of AT tasks. Tasks 4–6 were presented neither in AT nor MT and were new for the trained subjects. The verification test comprised both laboratory signals (tasks 1–3) and actual environmental signals. Thus it was a good tool for assessment of training effectiveness in known (previously trained) and unknown (natural) acoustic situations. The sound material was presented at a level of 65 dB SPL via open headphones Sennheiser HD600. The test apparatus and commands were the same as those used in the auditory training. The verification test took 45 minutes [21]. Physical parameters of the verification test tasks are as follows (task; stimuli; parameters; subject):

- Pitch discrimination (task 1); pairs of tones, each repeated 10 times, random order of tones and pairs; (500, 501.25) Hz, (750, 751.625) Hz, (1000, 1002.50) Hz, tone duration and the interval between tones — 300 ms, 0.25% detuning of frequency in the pair corresponds to the frequency discrimination threshold [30]; point out the higher tone in the pair.

- Pitch and timbre categorization (task 2); pairs of harmonic multitones, random order of pairs, 15 pairs differed in pitch only, 12 pairs differed in timbre only, 13 pairs differed in pitch and timbre; (f_0 = 294 Hz, $3f_0$, $4f_0$, $5f_0$) — low pitch, dark timbre, (f_0 = 294 Hz, $4f_0$, $5f_0$, $6f_0$) — low pitch, bright timbre, (f_0 = 471 Hz, $3f_0$, $4f_0$, $5f_0$) — high pitch, dark timbre, (f_0 = 471 Hz, $4f_0$, $5f_0$, $6f_0$) — high pitch, bright timbre, signal duration and the interval between signals — 300 ms; point out the difference in the pair (in pitch or timbre only, both in timbre and pitch).

- Pitch memory (task 3); 20 sequences of 9 non-harmonic tones, random order of tones in the sequence; frequencies of non-harmonic tones: 440.0, 466.2, 493.9, 523.3, 554.4, 587.3, 622.3, and 659.3 Hz, tone duration and the interval between tones — 300 ms; point out the sequence with the first and the last sound were the same.

- Lateralization of a stationary sound source (task 4); the sound of a drum recorded in an anechoic room, 27 sound examples, 3 from each direction; sound directions, at angles $\alpha = n * 45°$, n = 0, 1,..., 7 in the horizontal plane, one sound from above a head, sound duration — 1 s; point out the direction of the sound.

- Lateralization of a moving sound source (task 5); the sound of a car passing in two opposite directions, 24 sounds, 3 for each path and direction; in front, behind and on either side of the subject; point out the direction and the path of the sound.

- Lateralization of two moving sound sources (task 6); the sound of two cars going in two opposite directions and on two opposite paths 12 sounds, 3 for each path and direction; paths: front-back, left-right directions: left-to-right, right-to-left, front-to-back, back-to-front; point out the direction and the path of both cars.

3. The subjects

The experiment was performed on a group of 55 participants (21 blind and 34 visually impaired) from the school for the blind and visually handicapped children in Owińska and Łódź. The group that took part in AT included 6 children aged 7 to 12 (5 girls and 1 boy; 3 of whom were blind and 3 visually impaired; mean age 10 years) and 10 teenagers aged 13 to 19 (5 girls and 5 boys, 5 of whom were blind; mean age 16 years).

The group that took part in MT comprised 10 children aged 7 to 12 (6 girls and 4 boys; 7 of them were blind and 3 visually impaired; mean age 11 years) and 10 adolescents aged 13–19 (4 girls and 6 boys, 2 of whom were blind; mean age 15 years). The results were compared with the performance of two control groups of visually handicapped or blind subjects of the same age as the groups studied. The control group (not trained) comprised 9 children aged 7–12 (2 girls and 7 boys, all visually handicapped; mean age 11 years) and 10 teenagers aged 13–19 (3 girls and 7 boys, 4 of whom were blind; mean age 16 years). All participants were free from neurological disorders and were otologically normal persons; their hearing loss did not exceed 25 dB HL for frequencies from the range 250–8000 Hz.

4. Results and analysis of the pre- and post-training verification test

Each subject performed the verification test twice. The participants from the groups subjected to AT and MT performed the test before the training and immediately after the four/five-week-long training, while the persons from the control group performed the test twice, at a four-week interval. Within this time interval, the control group was not subjected to any training.

The results of the verification test have been subjected to multiple factor analysis of variance, ANOVA [31]. Analysis of all results for the three groups of subjects

(AT-group, MT-group, and control group) was performed taking into account three factors: the type of test (pre-training test, post-training test, or the first and the second test), action taken (participation in the acoustic or music training or not), and type of task performed in the test. General effects were analyzed first, i.e. subjects were not divided into age groups and the question was whether there was any statistically significant difference between pre- and post-test results for AT-, MT- and control subjects. The analysis of variance (Snedecor F-Test, F-variance ratio, p-significance level) proved a statistically significant difference between the results of pre-training test and post-training test ($F(1,\ 636) = 9.463$; $p = 0.0022$). Statistically significant was also the interaction between the action (AT, MT, or no training) and the type of test ($F(2,\ 636) = 3.684$; $p = 0.02567$) which means that the results of a given type of test significantly depend on whether the subject participated in the training or not.

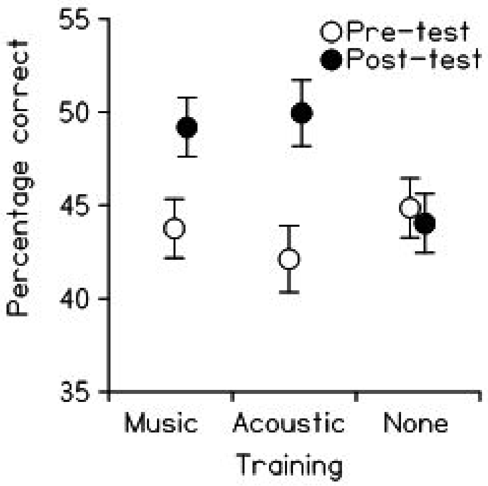

Fig. 1. Averaged results of pre- and post-training verification test for MT, AT, and control (not trained) subjects.

Figure 1 presents the global results of the pre-training and post-training test versus the action taken, for the persons subjected to MT, AT, and for the control group (not trained). Vertical bars in all figures indicate the standard error. As follows from the above analysis of the test results and Fig. 1, the subjects after AT and MT performed much better than those not subjected to any training. The difference is 5 and 8 percentage points for MT and AT, respectively, with the result being statistically significant ($p < 0.05$). For the control group, results of the first and second test are the same. Then, a similar analysis was executed for AT-, MT- and control subjects divided into age groups (cf. Fig. 2). The question was whether the age group was statistically significant and influenced verification test results. Three factors were analyzed: the task, the type of test (pre- or post-test), and the age group, as well as interactions between them.

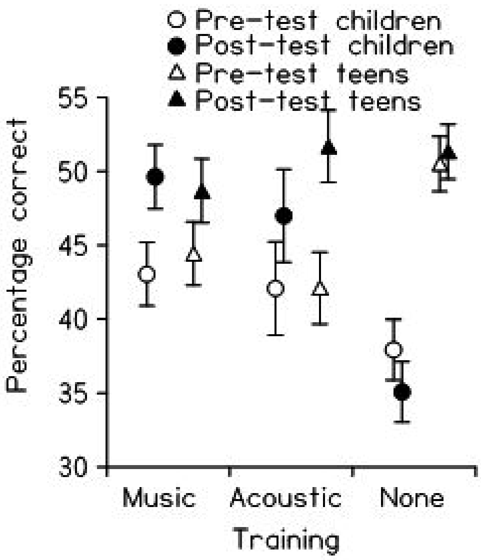

Fig. 2. Averaged results of pre- and post-training verification test for the MT, AT, and control subjects from both age groups.

ANOVA for the MT-group shows that statistically significant is the difference in results of the pre-and post-test ($F(1,\ 216) = 6.324$; $p = 0.012$) and the difference between tasks ($F(5,\ 216) = 10.502$; $p < 0.001$). There are no statistically significant differences between age groups and no interaction between factors. However, the NIR Fisher test shows that in the group of children, post-test results are statistically significantly better than pre-test results ($p = 0.013$). The corresponding difference is 7 percentage points. In the group of teenagers, the difference between pre- and post-results is not significant (cf. Fig. 2).

ANOVA for AT group shows that there is a statistically significant difference between the results of the pre- and post-test ($F(1,\ 168) = 6.698$; $p = 0.01$) and between test tasks ($F(5,\ 168) = 3.73$; $p = 0.003$). There are no statistically significant differences between the age groups and no interaction between the factors analyzed. However, the NIR Fisher test shows that in the group of teenagers, the post-test results are statistically significantly better than the pre-test ones ($p = 0.006$). The difference is 10 percentage points; such improvement in the test results after AT is not significant in the group of children (cf. Fig. 2).

ANOVA performed for the control group shows statistically significant difference between test tasks ($F(5,\ 216) = 7.469$; $p < 0.001$), age groups ($F(1,\ 216) = 54.182$; $p < 0.0001$), and interaction between tasks and age groups ($F(5,\ 216) = 4.306$; $p < 0.001$). ANOVA does not show any significant differences between pre- and post-test results or occurrence of interactions between the remaining factors analyzed in the control group.

The question is whether the perception benefits from AT for teenagers and from MT for children are of general nature or there are specific tasks with improved performance after the training.

A summary of statistical analysis of differences in pre- and post-training results for MT-, AT-, and control subjects for particular verification tasks is presented in Tables I–III.

TABLE I

Statistical analysis of results for MT-subjects. M — mean value (percent correct), SE — standard error (percent correct), pre — pre-test, post — post-test.

Task		Music training			
		Children		Adolescents	
		pre	post	pre	post
1. Pitch discrimination	M	43.33	51.33	55.67	54.17
	SE	4.95	4.54	2.79	4.53
	p	0.416667		0.880055	
2. Pitch/timbre categorization	M	37.67	45.00	34.00	35.83
	SE	7.28	5.77	7.66	7.37
	p	0.456356		0.855940	
3. Pitch memory	M	50.00	55.83	55.83	68.33
	SE	5.92	4.73	9.26	6.79
	p	0.553176		0.218650	
4. Lateralization of a stationary sound source	M	33.33	42.83	28.50	27.83
	SE	5.40	3.38	5.44	4.94
	p	0.335337		0.947358	
5. Lateralization of a moving sound source	M	53.33	61.50	41.33	53.00
	SE	8.47	6.61	7.24	11.14
	p	0.407081		0.250535	
6. Lateralization of two moving sound sources	M	45.33	60.83	36.83	49.67
	SE	11.30	10.08	6.53	7.77
	p	0.118309		0.206769	

AT was generally beneficial for teenagers and MT — for children, the results are shown in Fig. 3. Results for the control groups of children and adolescents are not presented in Fig. 3 as there are no statistically significant differences between pre- and post-test results.

Statistical analysis of results shows significant differences only for teenagers subjected to AT tasks 5 ($p = 0.05$) and 6 ($p < 0.001$). The tasks mentioned are the most “practical” ones in the whole verification test as they concern proper evaluation of motion of vehicles passing by. Therefore, we conclude that AT improves safety of visually handicapped teenagers in the urban environment. For musically trained children, no statistically significant differences in performance after and before training in realization of particular tasks are found, although the difference in results of pre- and post-training test in task 6 is at the significance level $p = 0.12$. However, a regular tendency towards higher scores in post-training results compared to pre-training results is observed. The observed tendency shows that tested auditory competences of MT-children are training-dependent and independent of hereditary factors, such as e.g. an absolute pitch which is independent of any music training [33]. In control groups, both for children and teenagers, no statistically significant differences in post- and pre-test results are observed (not shown in Fig. 3).

TABLE II

Statistical analysis of results for AT-subjects. M — mean value (percent correct), SE — standard error (percent correct), pre — pre-test, post — post-test.

Task		Acoustic training			
		Children		Adolescents	
		pre	post	pre	post
1. Pitch discrimination	M	34.83	53.00	48.10	51.70
	SE	6.84	2.91	3.95	2.87
	p	0.142460		0.643919	
2. Pitch/timbre categorization	M	48.83	45.33	46.90	46.50
	SE	6.72	6.33	3.15	4.81
	p	0.775609		0.959020	
3. Pitch memory	M	64.17	50.00	54.60	61.50
	SE	4.36	4.83	5.51	5.67
	p	0.251060		0.376285	
4. Lateralization of a stationary sound source	M	31.50	38.50	39.40	45.20
	SE	5.87	8.84	4.26	5.21
	p	0.569010		0.456810	
5. Lateralization of a moving sound source	M	37.67	50.17	34.90	50.00
	SE	12.34	13.99	4.59	8.65
	p	0.310593		0.054467	
6. Lateralization of two moving sound sources	M	35.50	45.00	28.80	55.40
	SE	8.23	13.61	5.94	8.12
	p	0.440099		0.000870	

TABLE III

Statistical analysis of results for control group-subjects. M — mean value (percent correct), SE — standard error (percent correct), pre — pre-test, post — post-test.

Task		Control group (no training)			
		Children		Adolescents	
		pre	post	pre	post
1. Pitch discrimination	M	50.11	45.67	43.64	51.64
	SE	3.45	3.71	3.74	1.54
	p	0.533761		0.216209	
2. Pitch/timbre categorization	M	37.11	39.22	51.73	49.00
	SE	4.43	4.13	3.03	6.20
	p	0.767472		0.672839	
3. Pitch memory	M	52.78	40.56	56.54	55.91
	SE	3.64	2.56	2.97	3.92
	p	0.087962		0.921499	
4. Lateralization of a stationary sound source	M	24.89	25.00	39.27	39.00
	SE	3.41	2.64	3.46	3.75
	p	0.987582		0.966312	
5. Lateralization of a moving sound source	M	31.44	34.33	54.09	58.54
	SE	4.86	6.20	7.15	7.29
	p	0.685783		0.490544	
6. Lateralization of two moving sound sources	M	31.22	25.67	57.91	54.09
	SE	5.11	4.08	6.22	7.59
	p	0.436777		0.554495	

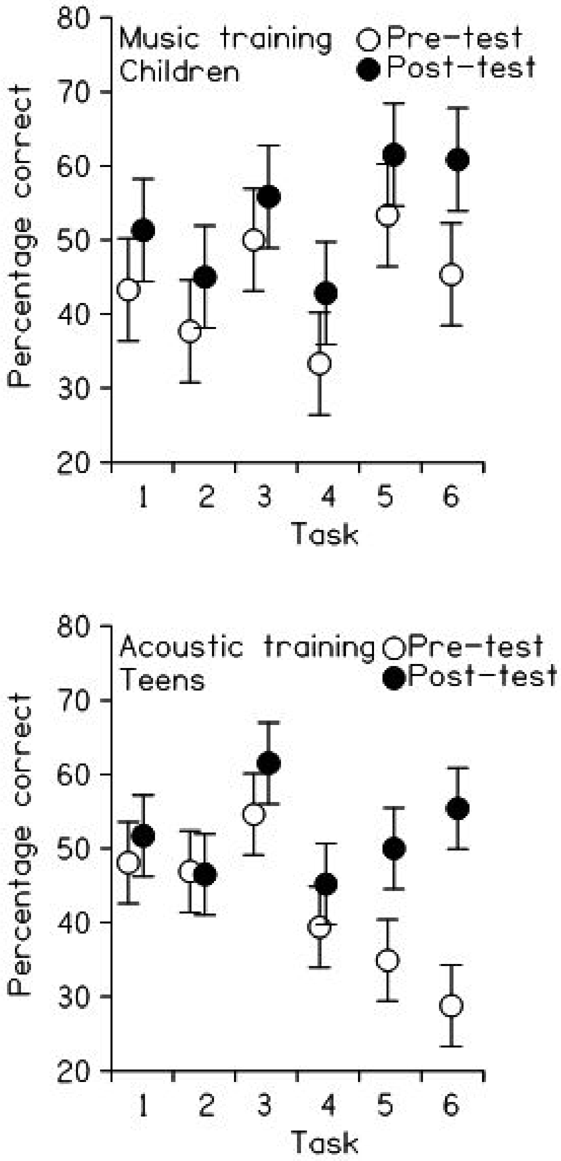

Fig. 3. Results of pre- and post-training verification test for particular tasks for MT children and AT teenagers.

Generally, the teenagers subjected to AT obtained better post-training test results than children (cf. Fig. 2). These differences can be explained by higher auditory competences (auditory attention, auditory scene analysis) of the older group of teenagers than those of the young children [3–6, 21]. The fact that the beneficiaries of MT (children) and AT (teenagers) performed significantly better after training in lateralization task 6 or 5 may be attributed to acquaintance with such sounds and better localization of sound sources by adult blinds than by sighted individuals reported in literature [32].

Thus, AT is beneficial for adolescents. Our results do not confirm extraordinary properties of the Tomatis method, although it appears to be generally good for small children to prepare them to listening and interpreting the environment relying of acoustic information. Another problem is the duration of AT and MT. The effects of AT on adolescents are spectacular in localization tasks after 4-week everyday training. Effects of MT on children are more general, with no test task privileged. It is likely that to obtain spectacular effects of MT, its duration should be longer, as it has been reported that the effect of a music training is correlated not only with physical stimulus but also with the perceptual experience of a subject [8].

5. Conclusions

After statistical analysis of the above-presented results, we have drawn the following conclusions.

1. The 4-week long auditory training proposed by us is beneficial for the blind or visually handicapped teenagers (13–19 year olds) as they obtained better results in the verification test after the training compared to those achieved before it in both types of verification tasks, i.e. in the tasks presented and not presented in AT. The greatest improvement in results after AT was made in the tasks of localization of environmental sounds.
2. Results of the 4-week long music training were not as spectacular as those of auditory training, but some tendency to general improvement in auditory abilities was noticed for the blind and visually impaired children (7–12 years old) in all verification tasks (not presented in the music training).
3. The effect of music training and auditory training was evaluated immediately after training sessions. It is difficult to assess the persistence of the training effect over time.
4. The time interval of 4 weeks did not change auditory competences of not trained control groups.

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