PAN
ARCHIVES OF ACOUSTICS
Vol. **40**, No. 3, pp. 337–349 (2015)



*DOI: 10.1515/aoa-2015-0037*

# Influence of Musical Experience of Blind and Visually Impaired Young Persons on Performance in Selected Auditory Tasks

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(*received April 10, 2014; accepted June 24, 2015*)

The impact of musical experience on results concerning sound perception in selected auditory tasks, such as pitch discrimination, pitch-timbre categorization and pitch memorization for blind and visually impaired children and teenagers is discussed. Subjects were divided into three groups: of those with no experience of music, with small musical experience and with substantial musical experience. The blind and visually impaired subjects were investigated, while sighted persons formed reference groups. To date no study has described impact of musical experience on results of such experiments for blind and visually impaired children and teenagers. Our results suggest that blind persons with musical experience may be more sensitive to frequency differences and differences in timbre between two signals as well as may have better short-term auditory memory than blind people with no musical experience. Musical experience of visually impaired persons does not necessary lead to better performance in all conducted auditory tasks.

**Keywords:** auditory tasks, blind and visually impaired children and teenagers, musical experience.

## 1. Introduction

According to some studies, blind people perform better than sighted individuals in tasks related to pitch discrimination and pitch-timbre categorization (Bogusz *et al.*, 2012a; Wan *et al.*, 2010; Gougoux *et al.*, 2004). As some of blind and visually impaired people are musically or auditory trained, it may be interesting to determine the effect of their musical experience on the ability to solve basic psychoacoustic tasks. A number of studies have shown that sighted musicians perform better than sighted non-musicians in tasks related to pitch discrimination (Tervaniemi *et al.*, 2005; Spiegel, Watson, 1984) and that classical musical training can lead to optimal or nearly optimal pitch discrimination performance (Micheyl *et al.*, 2006; Kishon-Rabin *et al.*, 2001). A possible reason for such performance is that the pitch is a fundamental dimension of auditory perception, which plays a basic role in music, for example: pitch variations over time are used to convey melodies. The results of a number of studies concerning timbre categorization by musically trained (various levels) and untrained listeners without vision dysfunction, have shown influence of musical training on correctness and time of performing tasks related to timbre categorization (Pitt, 1994; Crummer *et al.*, 1994; Seither-Preisler *et al.*, 2007). There are a number of papers about pitch memory in adult musicians and non-musician with normal vision (Rakowski, Rogowski, 2007; Rakowski, 2009; Gaab *et al,*, 2003; Moore *et al.*, 2007). Some studies suggest that training on a musical instrument is associated with improvements in working memory (Chan *et al.*, 1998; Franklin *et al.*, 2008; Ho *et al.*, 2003; Tierney *et al.*, 2008). The working memory ability is one of cognitive factors that is a linker between musical training and production of language sounds through changes in working memory capacity (Posedel *et al.*, 2012; Schellenberg, Peretz, 2008; Acheson, MacDonald, 2009). In the first study of this kind (Huntsinger, Jose, 1991) it was found that sighted musically experienced children performed better than musically inexperienced children on tonal memory. The adult blind subjects perform better than sighted ones at a variety of non-visual tasks, e.g. pitch discrimination, probably because they may be more susceptible to changes in brain functions induced by blindness (Wan *et al.*, 2010), e.g. for blind persons a larger tonotopic map in the auditory cortex was found, compared to the sighted reference group (Elbert *et al.*, 2002).

The study has been inspired by our previous papers (Bogusz *et al.*, 2012a; 2012b; 2012c; Bogusz-Witczak *et al.*, 2015; Furmann *et al.*, 2013; Hojan *et al.*, 2012; Skrodzka *et al.*, 2014; 2015) concerning acoustical assistance for the visually handicapped (blind and visually impaired) persons. Correct interpretation of characteristic features of a sound source, differences in sounds and focus of auditory attention on small differences in parameters of an acoustic signal is very important for blind and visually impaired children and teenagers. These abilities allow correct interpretation of environment by hearing and safe and effective navigation in urban environment.

Blind and visually impaired people are often a target group of research using 3D virtual sound space to present information that might be available only with vision. Blind persons are better in detecting movements in a horizontal plane and around the head, localization of static frontal audio sources and orientation in a 2D virtual audio space (Wersenyi, 2012). Roth *et al.* (2000) found that blind users play with the famous Concentration Game (representing the game elements in the 3D virtual space) differently, according to the nature of their blindness (the training task is more useful for congenitally blind people) as well as to their musical training (blind people with musical experience find it easier to play this game). Another example is creating a prototype for spatial orientation using a 3D scene sonification to present information about the environment. It is realised by creating the illusion of sounds originating from the locations of sonified scene elements like obstacles and planes (Bujacz *et al.*, 2012). Wersenyi, Repas (2014) carried out listening tests concerning different localization tasks in various environments (virtual reality, real life, free-field) with blind and blindfolded sighted participants. Results indicate that the blind subjects performance is generally not superior to that of the sighted subjects in all localization tasks. Blind individuals obtained significantly better results only in the tasks comprising echolocation during outdoor navigation and they had less front-back errors in virtual localization.

In this paper we discuss the impact of musical experience on the results concerning sound perception in selected auditory tasks, such as pitch discrimination, pitch-timbre categorization and pitch memorization (higher-level process) for blind and visually impaired children and teenagers. Each of two main groups of listeners i.e. blind and visually impaired subjects, were divided into one of three subgroups: those with no experience of music, those with small musical experience and those with substantial (large) musical experience. Most of our subjects have been blind/visually impaired since the first days of their life. The aim of the present paper was to investigate pitch discrimination, pitch-timbre categorization and pitch memory skills in blind, visual impaired and sighted reference groups of young participants (children and youths) with varying degrees of musical experience. No equivalent studies have been reported in literature yet. Our aim was to compare the results obtained by blind/ visually impaired subjects with no, small and substantial (large) musical experience and the results obtained for sighted groups with the same level of musical experience.

## 2. Subjects

A total of 21 blind/visually impaired persons (9 blind and 12 visually impaired), aged 7–17 years, took part in the study. Twenty of them took part in our previous investigation (Bogusz *et al.*, 2012a, 2012b). The group of visually impaired participants was non-homogenous, because the subjects had different degrees of vision loss and residual light perception, contrary to homogenous blind subjects. All handicapped subjects have had problems with vision ever since birth or soon after it, i.e. they were congenitally/early blind individuals. The only one subject (E1) having sight problems from the age of 4 was treated as congenitally blind individual. All participants were classified into one of three groups in respect of the musical experience: "none" – no experience of music, "small" – singing in the school choir amateur bands or playing melodic instruments for three years or less, "large" – education in a music school and singing or playing melodic instruments for no less than 4 years. None of the subjects had absolute pitch. Table 1 lists demographic characteristics of subjects with vision dysfunctions and information about their musical experience. For each blind/visually handicapped participant a sighted control person was recruited, corresponding in terms of age, gender, musical experience, preferred ear. All the subjects were volunteers, they were not paid for their services. The blind/visually impaired subjects were recruited from the Special Training and Education Centre for Blind Children in Owińska, Poland. None of the subjects had any significant hearing loss (as assessed by a tonal audiogram), and they were all free of neurological defects. They could stop tests at any time if they felt tired or uncomfortable.

Table 1. Characteristics of the congenitally blind (C), early-onset (E) and visually impaired (VI) subjects.

| Subject | Age of blindness onset [yrs] | Age at test [yrs] | Musical experience |
|---|---|---|---|
| C1 | 0 | 7 | none |
| C2 | 0 | 12 | none |
| C3 | 0 | 10 | small |
| C4 | 0 | 10 | small |
| C5 | 0 | 16 | small |
| C6 | 0 | 15 | large |
| C7 | 0 | 15 | large |
| C8 | 0 | 16 | large |
| E1 | 4 | 15 | none |
| V1 | 0 | 12 | none |
| V2 | 0 | 13 | none |
| V3 | 0 | 13 | none |
| V4 | 0 | 13 | none |
| V5 | 0 | 15 | none |
| V6 | 0 | 15 | none |
| V7 | 4 | 7 | small |
| V8 | 0 | 9 | small |
| V9 | 0 | 10 | small |
| V10 | 0 | 15 | small |
| V11 | 0 | 15 | small |
| V12 | 0 | 17 | small |

## 3. Experiments

Three experiments that concerned different aspects of auditory processing were performed: pitch discrimination, pitch-timbre categorization and pitch memorization. They were adopted from the experiments of Wan *et al.* (2010) and Bogusz *et al.* (2012a; 2012b). Sounds were prepared before the experiments in the Matlab environment. The experimental method of constant stimuli was used. In all three experiments sounds were presented in a random sequence via headphones Sennheiser HD600, to the preferred listener's ear, on a level comfortable to a subject. Basic level of the stimuli was fixed on 65 dB SPL, and could be changed by 5 dB. Timing of the experiments performed was as short as possible due to the fact that some of our subjects were children below ten years of age. Subjects were given a practice session prior to all experiments. The length of the practice session was adjusted to individual needs of the subjects (depending on age, concentration, intellectual development) and took ca 5 minutes. Subjects answered to the experimental tasks verbally and their answers were copied by the experimenter. As detailed acoustic parameters of the experiments were described earlier (Bogusz *et al.*, 2012a; 2012b), we recall only the most important information.

### *3.1. Pitch discrimination*

Frequencies of the tones used in the pitch discrimination experiment were presented in pairs, $(f, f+\Delta f)$, for $f = 500$, 750, 1000 Hz and 1500 Hz and $\Delta f = 2\%f$, $1\%f$, $0.5\%f$ and $0.25\%f$. Each trial contained two 300 ms tones, with an inter-tone interval of 300 ms and an attack and decay rate of 20 ms for each tone. Signals in a pair and pairs of signals were presented in random order. According to Ozimek (2002) and Moore (1999) for adult subjects with normal hearing just a noticeable difference in pitch is related to 0.2–0.3%$f$ discrepancy from frequency $f$ in the range of 500–1500 Hz. Thus, pairs $(f,\ f + 0.25\%)$ were the most difficult trials. The task of the subjects was to say which tone from the presented pair of tones was higher in pitch. Each pair of tones was presented 5 times. The whole experiment was composed of 160 pairs of tones (4 frequencies $\times$ 4 degrees of detuning $\times$ 2 order of tones in a pair $\times$ 5 presentations).

### *3.2. Pitch-timbre categorization*

Signals containing four tones of the same amplitude (basic frequency and three harmonics) were presented simultaneously. The fundamental frequency was 294 Hz and 417 Hz, for low- and high-pitch signal, respectively. The harmonics with numbers 3, 4 and 5 were added to the fundamental frequency to construct a signal dark in timbre. For the signal bright in timbre the harmonics with numbers 4, 5 and 6 were added to the fundamental frequency. Thus, the signals had two levels of pitch and two levels of timbre. Each trial contained two 300 ms signals with an inter-signals interval of 1500 ms and attack and decay rate of 20 ms. The task of the subjects was to assess whether the signals in a pair were similar in both pitch and timbre. They were asked to provide an answer whether the signals were similar in pitch and timbre, and if not – which feature of sound was different (pitch, timbre or both). Each pair of signals was presented 5 times, which gave 80 pairs in the whole experiment (4 signals $\times$ 4 signals $\times$ 5 presentations).

### *3.3. Pitch memorization*

Sequences of four or six tones were presented. The sequence comprised the first tone, the last tone and distracting tones not belonging to the musical pitch scale. Each trial contained 300 ms tones with an inter-tone interval 300 ms and the attack and decay rate of 20 ms The first tone in the sequence was 330, followed by 349, 370, 392, 415, 440, 466, 494, 523, 554, 587 or 622 Hz. The last tone in the sequence had exactly the same pitch as the first tone or diverged within the range of 41–55 Hz up or down. The frequencies of distracting tones diverged randomly within the range of $\pm 55$ Hz, eg. 4-tone sequence was (330, 341, 329,

330) Hz or (330, 366, 374, 277) Hz, for the sequence with first and last frequency equal or different, respectively The subjects were asked to determine whether the last and first tones had the same pitch. Each sequence was presented twice to each subject. Each part of this experiment (for 4 and 6 tones in sequence) was composed by 72 sequences (12 first tones × 3 options for last tones: the same, lower, higher pitch × 2 presentations).

## 4. Results

Similarly to Wan *et al.* (2010) and Bogusz *et al.* (2012a; 2012b), the proportion of correct answers was a primary dependent variable for pitch discrimination, pitch-timbre categorization and pitch memorization experiments. In each experiment we asked three questions: (a) is there any advantage of the blind/visually impaired subjects over respective sighted groups with respective musical experience, (b) is there any advantage of the blind subjects over visually impaired subjects with the same musical experience (c) is there any advantage of the blind/visually impaired subjects with substantial (large) musical experience over blind/visually impaired subjects with small musical experience.

General effects of vision dysfunction and musical experience on results of experiments were analysed first. Results were analysed for two groups of subjects: with vision dysfunctions (blind and visually impaired merged) and sighted. The results were subjected to multiple factor analysis of variance, ANOVA, with three factors: vision (dysfunction, sighted), musical experience (no, small, large) and experiment (pitch discrimination, pitch-timbre categorization, pitch memorization). The analysis of variance (Snedecor F-Test, F-variance ratio, p-significance level) proved a statistically significant difference between the results of subjects with various musical experience ($F(2{,}401) = 18.33$; $p = 0.00$). No statistically significant differences were found between the results obtained by the persons with vision dysfunction and sighted $F(1{,}401) = 2.87$; $p = 0.09$) and between different experiments ($F(2{,}401) = 0.93$; $p = 0.40$). Taking into regard the above results, the data were subjected to detailed analysis with the t-Student test for unrelated variables, which permitted comparison of mean results obtained by the groups of subjects distinguished according to the level of musical experience and vision (the blind, visually impaired and sighted). The results were analysed separately for each experiment and for each level of difficulty of a given task.

The assumption of the equality of variances was verified with the Levene and Brown-Forsythe test. There were no statistically significant differences in variances in any compared pair of groups.

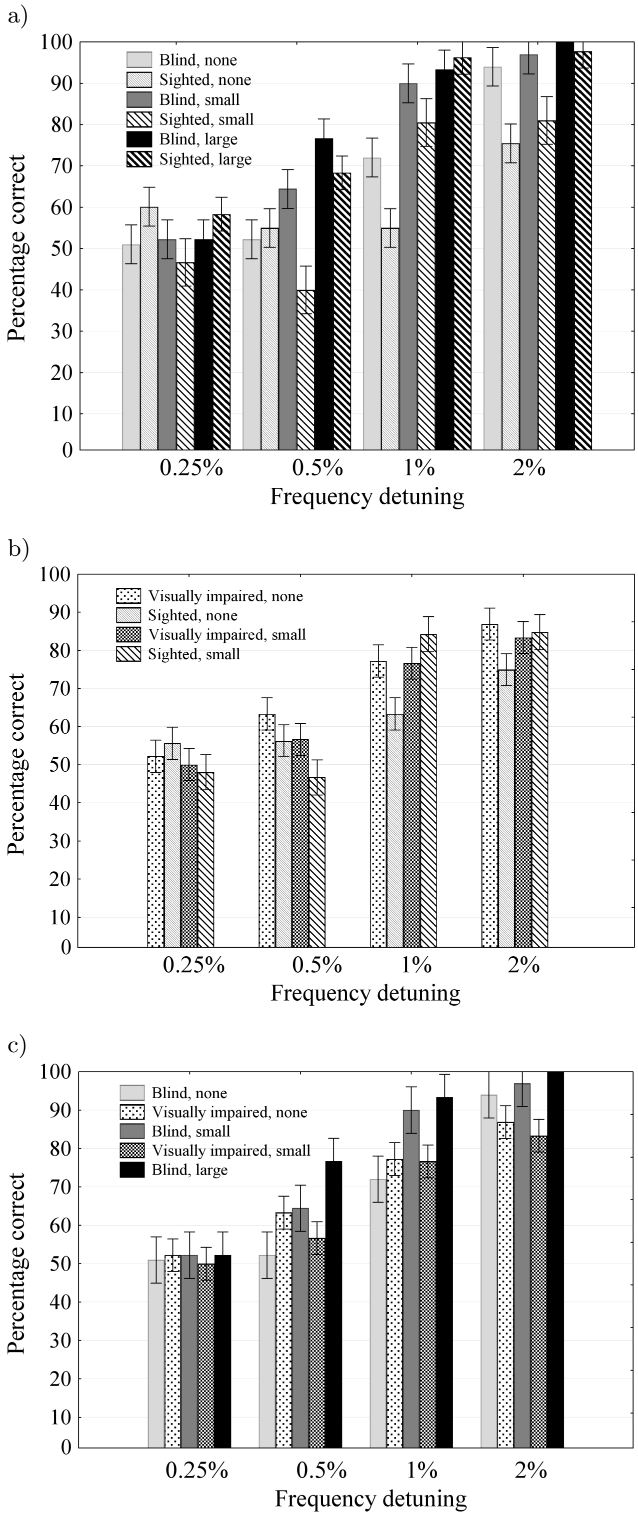


Fig. 1. Means and standard errors of percentage of correct answers in the pitch discrimination task for: a) three groups of blind subjects (none, small, substantial (large) musical experience) and corresponding sighted reference groups, b) two groups of visually impaired subjects (none, small musical experience) and the corresponding sighted reference groups, c) three groups of blind subjects (none, small, substantial (large) musical experience) and two groups of visually impaired subjects (none or small musical experience).

### *4.1. Pitch discrimination*

Four frequency detunings, i.e.: 0.25%, 0.5%, 1%, and 2% from the base tones were used and four groups of subjects, i.e.: blind, visually impaired and two sighted reference groups (one for blind and one for visually impaired subjects) were investigated. The group of blind persons and two sighted reference groups included individuals without experience in music, with small and substantial (large) musical experience. The group of visually impaired subjects comprised only listeners without and with small musical experience. Results of the pitch discrimination experiment are shown in Fig. 1. The results obtained for two groups of blind subjects with various musical experience and the corresponding reference groups are presented in Fig. 1a, while Fig. 1b shows the results for visually impaired subjects and the corresponding reference groups. The results for three groups of blind subjects and three groups of visually impaired subjects, with different musical experience are shown in Fig. 1c. Error bars in all presented figures indicate standard errors of means.

The statistical significance of difference in means revealed for the tested groups of subjects in the pitch discrimination task is shown in Table 2. There were no statistically significant differences for all groups for frequency differences 0.25%. Results not statistically significant are omitted in Tables 2–4.

### *4.2. Pitch-timbre categorization*

Four conditions were used: no difference in pitch and timbre, difference in pitch only, difference in timbre only, difference in both pitch and timbre and four groups of subjects, i.e.: blind, visually impaired and two sighted reference groups, with different musical experience, i.e.: substantial (large) (except of visually impaired), small and none, were investigated. The results of the pitch-timbre categorization experiment are shown in Fig. 2 in the same manner as results of the pitch discrimination experiment. The statistical significance of difference in means revealed for pairs of tested groups of subjects in the pitch-timbre categorization experiment is shown in Table 3.

Table 2. Statistical significance of differences in the mean results between groups of tested subjects in the pitch discrimination task. B – blind subjects, VI – visually impaired subjects, VH – visually handicapped subjects, i.e. B + VI, R – adequate, sighted reference group; subscripts no, small, large refer to musical experience.

| Compared groups | Frequency difference | | |
|---|---|---|---|
| | $0.5\%f$ | $1\%f$ | $2\%f$ |
| $B_{small}$ and $R_{small}$ | $t_{(4,0.048)} = 2.34$ | | $t_{(4,0.03)} = 3.35$ |
| $B_{no}$ and $B_{small}$ | | $t_{(4,0.03)} = 3.40$ | |
| $B_{no}$ and $B_{large}$ | $t_{(4,0.04)} = 2.45$ | $t_{(4,0.02)} = 3.58$ | |
| $VI_{no}$ and $R_{no}$ | | $t_{(10,0.04)} = 2.37$ | $t_{(10,0.045)} = 2.17$ |
| $VH_{no}$ and $R_{no}$ | | $t_{(16,0.01)} = 3.05$ | $t_{(16,0.01)} = 3.08$ |
| $VH_{small}$ and $R_{small}$ | $t_{(16,0.03)} = 2.42$ | | |

Table 3. Statistical significance of differences in the mean results between groups of tested subjects in the pitch-timbre categorization task. B – blind subjects, VI – visually impaired subjects, VH – visually handicapped subjects, i.e. B + VI, R – adequate, sighted reference group; subscripts no, small, large refer to musical experience. Bold fonts indicate results bordering on statistical significance.

| Compared groups | Condition | | | |
|---|---|---|---|---|
| | No difference in pitch and timbre | Difference in pitch only | Difference in timbre only | Difference in both pitch and timbre |
| $B_{large}$ and $R_{large}$ | | | $t_{(4,0.0002)} = 13.00$ | |
| $B_{no}$ no and $B_{large}$ | | | | $\mathbf{t_{(4,0.08)} = -2.35}$ |
| $B_{small}$ and $B_{large}$ | | | $t_{(4,0.016)} = -4.00$ | $t_{(4,0.03)} = -3.19$ |
| $B_{smal}$ and $R_{small}$ | | | | $t_{(4,0.04)} = -1.84$ |
| $VI_{no}$ and $R_{no}$ | $t_{(10,0.01)} = 3.03$ | | | |
| $VI_{small}$ and $R_{small}$ | | $\mathbf{t_{(10,0.054)} = 2.18}$ | | |
| $VH_{no}$ and $R_{no}$ | $t_{(16,0.001)} = 3.99$ | | | |
| $VH_{small}$ and $R_{small}$ | | $t_{(16,0.01)} = 3.04$ | | $t_{(16,0.02)} = -2.51$ |

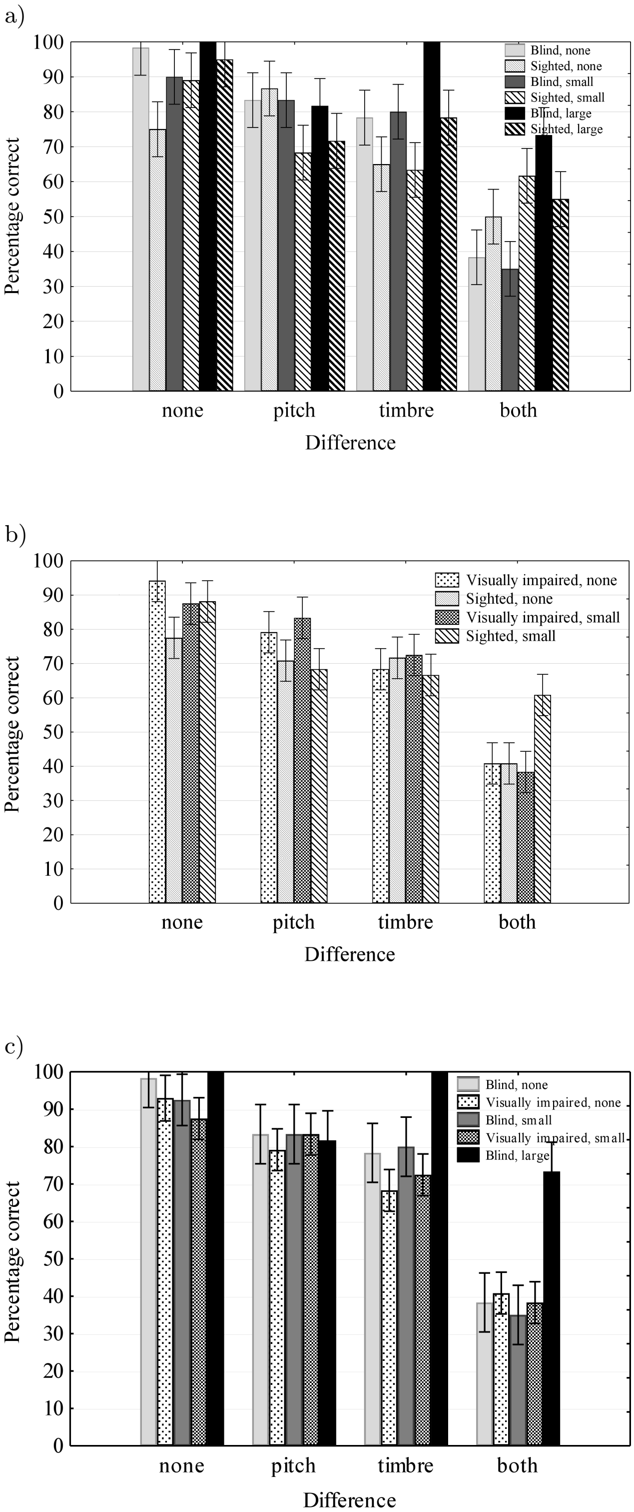


Fig. 2. Means and standard errors of percentage of correct answers in the pitch-timbre categorization task for: a) three groups of blind subjects (none, small, substantial (large) musical experience) and corresponding sighted reference groups, b) two groups of visually impaired subjects (none, small musical experience) and corresponding sighted reference groups, c) three groups of blind subjects (none, small, substantial (large) musical experience) and two groups of visually impaired subjects (none or small musical experience).

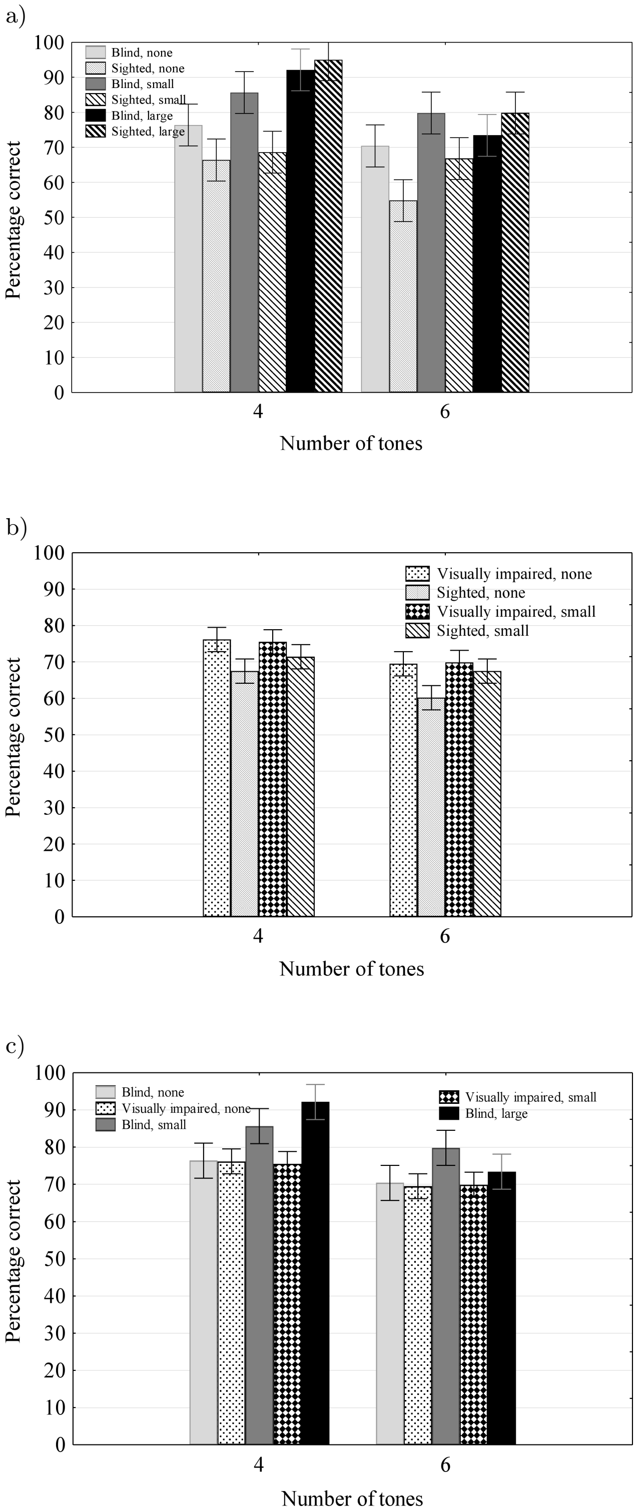


Fig. 3. Means and standard errors of percentage of correct answers in the pitch memorization task for: a) three groups of blind subjects (none, small, substantial (large) musical experience) and corresponding sighted reference groups, b) two groups of visually impaired subjects (none, small musical experience) and corresponding sighted reference groups, c) three groups of blind subjects (none, small, substantial (large) musical experience) and two groups of visually impaired subjects (none or small musical experience).

Table 4. Statistical significance of differences in the mean results between groups of tested subjects in the pitch memorization task. B – blind subjects, VI – visually impaired subjects, VH – visually handicapped subjects, i.e. B + VI, R – adequate, sighted reference group; subscripts no, small, large refer to musical experience. Bold fonts indicate results on a border of statistical significance.

| Compared groups | Number of tones | |
|---|---|---|
| | 4 | 6 |
| $B_{no}$ and $R_{no}$ | | $t_{(4,0.01)} = 5.17$ |
| $B_{small}$ and $R_{small}$ | $t_{(4,0.049)} = 2.80$ | $\mathbf{t_{(4,0.07)} = 2.47}$ |
| $B_{no}$ and $B_{large}$ | $t_{(4,0.03)} = -3.17$ | |
| $B_{small}$ and $VI_{small}$ | $\mathbf{t_{(7,0.051)} = 2.34}$ | $t_{(7,0.03)} = 2.72$ |
| $VH_{no}$ and $R_{no}$ | $\mathbf{t_{(16,0.06)} = 2.02}$ | $t_{(16,0.01)} = 3.06$ |
| $VH_{small}$ and $R_{small}$ | $t_{(16,0.03)} = 2.38$ | $\mathbf{t_{(16,0.08)} = 1.87}$ |

### *4.3. Pitch memorization*

Sound sequences having 4 or 6 tone components and four groups of subjects, i.e.: blind, visually impaired and two sighted reference groups, with different musical experience, i.e.: substantial (except of visually impaired), small and none, were investigated. The results of the pitch memorization experiments are shown in Fig. 3 in the same manner as those of the pitch discrimination and pitch-timbre categorization experiment. A statistical significance of difference in means revealed for tested groups of subjects in the pitch memorization experiment is shown in Table 4.

## 5. Discussion

The first two experiments: pitch discrimination and pitchtimbre categorization relied on basic perceptual skills, while the third experiment, i.e. pitch memorization was related to a higher-level process, i.e. to working memory. Results from all experiments are nonhomogeneous for all levels of difficulty (four frequency differences in the pitch discrimination experiment, four condition in the pitch-timbre categorization experiment and two numbers of tones in the pitch memorization experiment). Therefore discussion is performed separately for subsequent experiments. The collected results for the pitch discrimination, pitch-timbre categorization and pitch memorization experiments are shown in Tables 5–7 respectively. In Tables 5–7 conditions which realisation gave statistically significant results are specified. Bottom parts of Tables 2–7 show the results for the groups of "visually handicapped" subjects, VH, comprising blind and visually impaired subjects with appropriate musical experience and for the groups of appropriate reference participants. The visually impaired persons with substantial musical experience did not take part in the study.

Table 5. Summary of pitch discrimination results for conditions with statistically significant differences in means, all – comparable results in all tested conditions, B – blind subjects, VI – visually impaired subjects, VH – visually handicapped subjects, i.e. B + VI, R – adequate, sighted reference group; subscripts no, small, large refer to musical experience.

| | Pitch discrimination experiment | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $B_{no}$ | $B_{small}$ | $B_{large}$ | $VI_{no}$ | $VI_{small}$ | $R_{B, no}$ | $R_{B, small}$ | $R_{B, large}$ | $R_{VI, no}$ | $R_{VI, small}$ | $R_{B, no+VI,no}$ | $R_{B,small+VI,small}$ |
| $B_{no}$ | | 1% | 0.5%, 1% | all | | all | | | | | | |
| $B_{small}$ | | | all | | all | | 0.5%, 2% | | | | | |
| $B_{large}$ | | | | | | | | all | | | | |
| $VI_{no}$ | | | | | all | | | | 1%, 2% | | | |
| $VI_{small}$ | | | | | | | | | | all | | |
| $B_{no} + VI_{no}$ | | | | | | | | | | | 1%, 2% | |
| $B_{small} + VI_{small}$ | | | | | | | | | | | | 0.5% |

Table 6. Summary of pitch-timbre categorization results for conditions with statistically significant differences in means, all – comparable results in all tested conditions, none – no comparable results in all tested conditions, B – blind subjects, VI – visually impaired subjects, VH – visually handicapped subjects, i.e. B + VI, R – adequate, sighted reference group; subscripts no, small, large refer to musical experience. X – condition in which sighted subjects performed better than blind listeners.

| Pitch-timbre categorization experiment | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $B_{no}$ | $B_{small}$ | $B_{large}$ | $VI_{no}$ | $VI_{small}$ | $R_{B,\ no}$ | $R_{B,\ small}$ | $R_{B,\ large}$ | $R_{VI,\ no}$ | $R_{VI,\ small}$ | $R_{B,\ no+VI,no}$ | $R_{B,small+VI,small}$ |
| $B_{no}$ | | all | all | all | | all | | | | | | |
| $B_{small}$ | | | timbre both | | all | | both (X) | | | | | |
| $B_{large}$ | | | | | | | | timbre | | | | |
| $VI_{no}$ | | | | | all | | | | none | | | |
| $VI_{small}$ | | | | | | | | | | all | | |
| $B_{no} + VI_{no}$ | | | | | | | | | | | none | |
| $B_{small} + VI_{small}$ | | | | | | | | | | | | pitch, both (X) |

Table 7. Summary of pitch-memory results for conditions with statistically significant differences in means, all – comparable results in all tested conditions, B – blind subjects, VI – visually impaired subjects, VH – visually handicapped subjects, i.e. B + VI, R – adequate, sighted reference group; subscripts no, small, large refer to musical experience.

| Pitch memory experiment | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $B_{no}$ | $B_{small}$ | $B_{large}$ | $VI_{no}$ | $VI_{small}$ | $R_{B,\ no}$ | $R_{B,\ small}$ | $R_{B,\ large}$ | $R_{VI,\ no}$ | $R_{VI,\ small}$ | $R_{B,\ no+VI,no}$ | $R_{B,small+VI,small}$ |
| $B_{no}$ | | all | 4-tone | all | | 6-tone | | | | | | |
| $B_{small}$ | | | all | | 6-tone | | 4-tone | | | | | |
| $B_{large}$ | | | | | | | | all | | | | |
| $VI_{no}$ | | | | | all | | | | all | | | |
| $VI_{small}$ | | | | | | | | | | all | | |
| $B_{no} + VI_{no}$ | | | | | | | | | | | 6-tone | |
| $B_{small} + VI_{small}$ | | | | | | | | | | | | 4-tone |

### *5.1. Blind, visually impaired and sighted group differences across different musical experience*

*Pitch discrimination experiment*

In the pitch discrimination experiment the following differences and similarities were found for compared pairs of groups and experimental conditions.

- The blind group with substantial (large) musical experience ($B_{large}$) performed better than the blind group with no musical experience ($B_{no}$), for $\Delta f = 0.5\% f$ and $1\% f$.
- The blind group with small musical experience ($B_{small}$) performed better than the blind group with no musical experience ($B_{no}$), for $\Delta f = 1\% f$ and better than its reference group ($R_{B,\, small}$), for $\Delta f = 0.5\% f$ and $2\% f$.
- The visually impaired group with no musical experience ($VI_{no}$) obtained better results than its reference group ($R_{VI,\, no}$), for $\Delta f = 1\% f$ and $2\% f$.
- There were no differences in means of the results for the pairs of groups compared ($B_{small}$, $B_{large}$), ($B_{large}$, $R_{B,\, large}$), ($VI_{small}$, $R_{VI,\, small}$), ($VI_{small}$, $VI_{no}$), ($B_{no}$, $VI_{no}$), ($B_{small}$, $VI_{small}$) and ($B_{no}$, $R_{B,\, no}$) for all tested frequency differences. For $\Delta f = 0.25\% f$ correct answers oscillated around the chance level (50% of correct responses) for all groups. For adult subjects with normal hearing just a noticeable difference in pitch was related to a 0.2–0.3% detuning from frequency in the range of 500–1500 Hz (Moore, 1999). Therefore, we expected that the smallest frequency difference might be difficult for the children and youths to notice. For $\Delta f = 2\% f$ (the easiest condition) the results of blind and visually impaired subjects exceeded 80% of correct answers. Thus, the frequency differences $\Delta f = 0.5\% f$ and $1\% f$ were the distinguishing conditions.

Generally, blind and visually impaired subjects with substantial (large) musical experience performed similarly to their sighted counterparts, Fig. 1a,b and Table 2 and 5, with statistically insignificant differences between groups. The group $B_{large}$ scored higher than $VI_{small}$ group for all frequency differences tested, but the differences between the groups for all tested conditions were not statistically significant. Thus, superior performance of blind subjects with large musical experience ($B_{large}$) over the sighted reference group ($R_{B,\, large}$) and the groups of visually impaired subjects ($VI_{no}$ and $VI_{small}$) was not corroborated in our pitch discrimination experiment. As no equivalent studies have been reported in literature yet we do not have any results to refer to. However, superior performance of $B_{large}$ group over the corresponding $R_{B,\, large}$ and $VI_{small}$ groups of subjects was expected on the basis of earlier papers reporting better performance in the pitch discrimination task of blind subjects than sighted individuals (Bogusz *et al.*, 2012a; Wan *et al.*, 2010; Gougoux *et al.*, 2004) and sighted musicians than sighted non-musicians (Tervaniemi *et al.*, 2005; Spiegel, Watson, 1984).

*Pitch-timbre categorization experiment*

In the pitch-timbre categorization experiment the following differences and similarities were found for compared pairs of groups and experimental conditions.

- $B_{large}$ group obtained significantly better results that $B_{small}$ group in realisation of the conditions "difference in timbre only" and "difference in both pitch and timbre". Moreover, $B_{large}$ group outperformed $B_{no}$ group in the most difficult condition of identification of "difference in both pitch and timbre", and the result was close to the border of significance ($p = 0.08$).
- $B_{large}$ group outperformed $R_{B,\, large}$ subjects in the condition of identification of "difference in timbre only".
- $VI_{no}$ group obtained better results than its reference group $R_{VI,\, no}$ in the easiest condition "no difference in pitch and timbre".
- $VI_{small}$ group obtained better results than its reference group, $R_{VI,\, small}$, in the condition "difference in pitch only" (result was on the border of significance, i.e. $p = 0.054$).
- Surprisingly, in the condition "difference in pitch and timbre" the reference groups with small musical experience ($R_{B,\, small}$ and $R_{VI,\, small}$) had a better performance than $B_{small}$ and $VI_{small}$ groups. This situation, when the results of sighted people are significantly better than those for people with vision dysfunction, occurred just for this experiment and in the most difficult condition. In this task the percentage of correct answers by sighted people was about 60% and that given by persons with vision loss (blind and visually impaired) was less than 40%.
- There were no differences in means of the results obtained by the remaining groups of subjects and tested conditions.

Generally, blind subjects with substantial (large) musical experience performed better than their sighted counterparts in two most difficult conditions "difference in timbre" (statistically significant), and "difference in pitch and timbre" (the result is not statistically significant), Fig. 2a, Table 3 and 6. Moreover, $B_{large}$ group outperformed all remaining groups with vision problems in the tasks "difference in pitch and timbre" and "difference in timbre", Fig. 2c, Table 3 and 6. Such performance was not observed for both visually impaired groups ($VI_{no}$ and $VI_{small}$). Thus, superior performance of $B_{large}$ subjects over the sighted reference group ($R_{B,\, large}$) and both groups of visually impaired subjects ($VI_{no}$ and $VI_{small}$) was confirmed in our pitch-timbre categorization experiment for the two most difficult conditions. Such performance of $B_{large}$ group was expected on the basis of earlier reports (Bogusz *et al.*, 2012a; Wan *et al.*, 2010; Gougoux *et al.*, 2004; Tervaniemi *et al.*, 2005; Spiegel, Watson, 1984).

*Pitch memorization experiment*

In the pitch memorization experiment the following differences and similarities were found for compared pairs of groups and tested sequences of tones.

- $B_{large}$ subjects obtained significantly better results than $B_{no}$ group for the 4-tone sequence.
- $B_{no}$ individuals performed better than the sighted reference group, $R_{B,\,no}$, for the 6-tone sequence.
- $B_{small}$ group outperformed $R_{B,\,small}$ group and $VI_{small}$ group for sequences consisting of 4 and 6 tones (on the border of significance, i.e. $p = 0.07$ and $p = 0.051$ respectively).
- There were no statistically significant differences in means of the results obtained by the remaining groups of subjects and tone sequences.

The pitch memorization experiment was the easiest experiment for the subjects. The performance of blind and visually impaired subjects in both tested conditions was no worse than 70% correct responses. The performance of blind, visually impaired subjects and their reference groups was similar for all levels of musical experience, Fig. 3, Table 4 and 7. Superior performance of $B_{large}$ subjects was not revealed. The result showing that the performance of blind and visually impaired young persons in pitch memorization experiment with 4- and 6-tone sequences was almost constant, was reported earlier (Bogusz *et al.*, 2012b). The reports suggesting that musical training is associated with improvements in working memory (Chan *et al.*, 1998; Franklin *et al.*, 2008; Ho *et al.*, 2003; Tierney *et al.*, 2008) have not been confirmed.

## 5.2. *Visually handicapped (blind+visually impaired) and sighted group differences across different musical experience*

In the pitch discrimination and pitch-timbre categorization experiments, the Student's t-test showed that no statistically significant differences in means were found between blind and visually impaired subjects for all compared groups with definite musical experience and for all tasks. Therefore, we have decided to analyse the results for blind and visually impaired participants together (separately for each experiment), despite the fact that in the pitch memorization experiment for the 6-tone sequence, statistically significant difference was observed ($p = 0.03$) between blind and visually impaired subjects with small musical experience. From now on the combined groups of blind and visually impaired subjects (for a given level of musical experience) are called visually handicapped (VH) groups. Appropriate reference groups were created as well. The results are shown in Fig. 4 and in bottom parts of Tables 2–7.

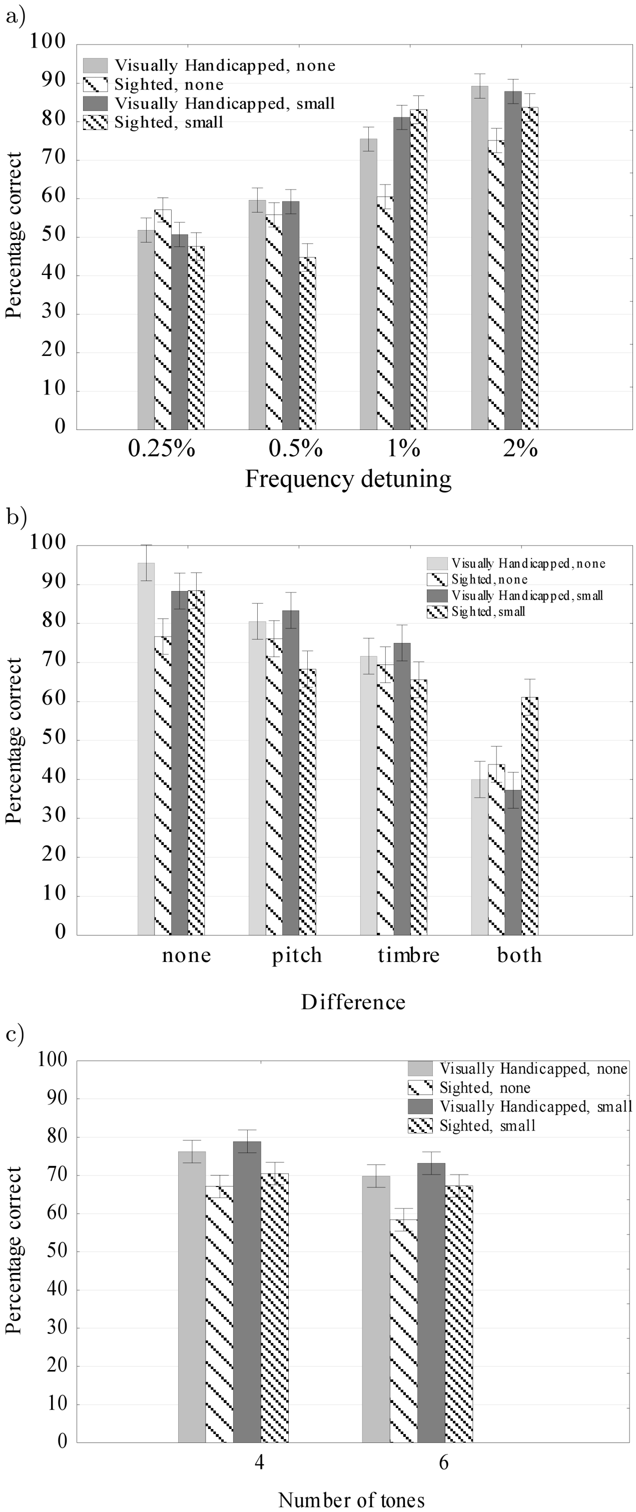


Fig. 4. Means and standard errors of percentage of correct answers in: a) the pitch discrimination task, b) the pitch-timbre categorization task, c) pitch memorization task for two groups of visually handicapped subjects (combined blind and visually impaired groups) with none or small musical experience and corresponding sighted reference groups.

In the pitch discrimination experiment, $VH_{no}$ group performed better than their sighted counterparts ($R_{VH,\ no}$), for $\Delta f = 1\% f$ and $2\% f$. $VH_{small}$ group performed better than its reference group ($R_{VH,\ small}$) for $\Delta f = 0.5\% f$.

In the pitch-timbre categorization experiment, $VH_{small}$ subjects obtained better results than $R_{VH,\ small}$ subjects, in the condition "difference in pitch only". In the condition "difference in pitch and timbre" the sighted group $R_{VH,\ small}$ obtained better results than $VH_{small}$ subjects, similarly to the results of the pitch-timbre categorization experiment for blind and visually impaired subjects analysed separately. $VH_{no}$ group obtained a better score than $R_{VH,\ no}$ sighted group in the condition "no difference in pitch and timbre".

In the pitch memorization experiment, the groups $VH_{small}$ and $VH_{no}$ showed better performance than the sighted referenced groups for the 4- and 6-tone sequence (but for two groups the results were on the border of significance, i.e. for the 4-tone sequence and no musical experience $p = 0.06$ and for the 6-tone sequence and small musical experience $p = 0.08$), Fig. 4c.

From the above presented results it is clear that the superior performance of blind, visually impaired or VH subjects over sighted reference groups with respective levels of musical experience is not confirmed for all experiments and all tested conditions, but for selected levels of the tasks. This general observation confirms our results reported earlier (Bogusz *et al.*, 2012a; 2012b). A possible explanation is the age of blind and visually impaired subjects (Table 1). Nine subjects had no musical experience, nine reported small experience with music and the remaining ones declared substantial (large) musical experience. Their age was 7–15, 7–17 and 15–16 years respectively. Subjects with no and small musical experience were in the majority of tested individuals. However, blind subjects (15–16 years old) with substantial (large) musical experience performed significantly better than the remaining subjects at least in the pitch-timbre categorization experiment in the two most difficult conditions "simultaneous difference in pitch and timbre" and "difference in timbre". This observation can be explained by the higher auditory (auditory attention, auditory scene analysis) and musical competences (Gougoux *et al.*, 2004; 2005; Wan *et al.*, 2010; Bogusz-Witczak *et al.*, 2015; Skrodzka *et al.*, 2015). Acquisition of auditory competences is a developmental process lasting up to 16–17 years of age. Also musical training needs time to be effective in improving auditory skills (Micheyl *et al.*, 2006; Kishon-Rabin *et al.*, 2001; Seither-Preisler *et al.*, 2007; Franklin *et al.*, 2008; Ho *et al.*, 2003; Tierney *et al.*, 2008). Moreover, visually impaired subjects with small musical experience generally did not perform as well as blinds, and their performance was similar to that of the sighted reference counterparts. For all frequency differences in the pitch discrimination, all conditions of the pitch-timbre categorization and all numbers of tones in the pitch memorization experiments, the results for visually impaired subjects with small and none musical experience were similar. The observed differences between blind and visually impaired persons reported here could be due to fact that the visually impaired persons, in contrast to the blind ones, always used the remainders of sight. Thus, musical experience is not necessarily a factor differentiating auditory skills of blind/visually impaired children and teenagers, but a general tendency "the greater musical experience, the greater the auditory competences" is clearly confirmed by our results.

## 6. Conclusions

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

1. Superior performance of blind subjects with substantial (large) musical experience over sighted reference groups and visually impaired listeners with the same level of musical experience has been confirmed in the two most difficult conditions in the pitch-timbre categorization experiment. Thus our results suggest that musical experience can lead to improved performance in some auditory tasks but the musical training should be longer than 4 years.
2. Musical experience of visually impaired persons does not lead to a better performance in any auditory tasks.
3. Higher scores of blind participants could be due to intermodal plastic changes in the brain as a result of complete visual deprivation.
4. Visually handicapped subjects with small and none musical experience performed better than their reference groups in the pitch memory experiment.
5. Musical experience is not necessarily a factor differentiating auditory skills of blind/visually impaired children and teenagers, but a general tendency described by the expression "the greater the musical experience, the greater the auditory competences" has been clearly confirmed by our results.
6. Finally, it must be pointed out that the ability to recognise small changes in acoustic parameters of signals and then correct interpretation of characteristic features of a sound source can provide information about changes in the surrounding environment. It is very important for safe and independent spatial orientation and mobility of blind people in an urban environment.

## Acknowledgments

We are very indebted to the teachers and pupils of the Special Training and Education Centre for Blind Children in Owińska, Poland for their work and cooperation during the experiments. The work was partially supported by the National Science Centre (Grant no. 2012/05/B/HS6/03863).

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