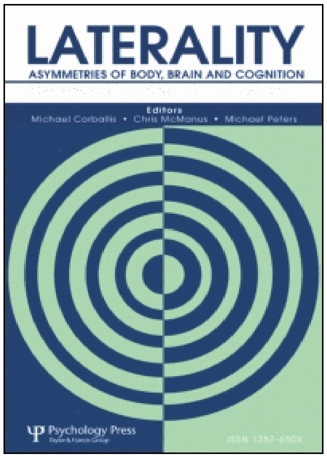

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The influence of musical experience on lateralisation of auditory processing

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The influence of musical experience on lateralisation of auditory processing

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The influence of musical experience on free-recall dichotic listening to environmental sounds, two-tone sequences, and consonant-vowel (CV) syllables was investigated. A total of 60 healthy right-handed participants were divided into two groups according to their active musical competence ("musicians" and "non-musicians"). In both groups, we found a left ear advantage (LEA) for nonverbal stimuli (environmental sounds and two-tone sequences) and a right ear advantage (REA) for CV syllables. Dichotic listening to environmental sounds was uninfluenced by musical experience. The total accuracy of recall for two-tone sequences was higher in musicians than in non-musicians but the lateralisation was similar in both groups. For CV syllables a lower REA was found in male but not female musicians in comparison to non-musicians. The results indicate a specific sex-dependent effect of musical experience on lateralisation of phonological auditory processing.

The dichotic listening paradigm—in which two different auditory stimuli are presented at the same time, one to each ear—has been widely used to study the nature of hemispheric specialisation. If phonological stimuli are presented dichotically, a right ear advantage (higher accuracy of recall for stimuli presented to the right ear, REA) is typically found (Kimura, 1961; for a review see Bryden, 1988). This has been interpreted as a consequence of left hemisphere specialisation for the processing of language (Hugdahl, 2003;

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Tervaniemi & Hugdahl, 2003). In contrast, a left ear advantage (LEA) is usually found for nonverbal stimuli, such as musical chords and melodies (Kimura, 1964; for a review see Peretz & Morais, 1988), environmental sounds (Kraft, 1982; Kraft, Harper, & Nickel, 1995), and emotion-related sounds (Obrzut, Bryden, Lange, & Bulman-Fleming, 2001; see also Techentin & Voyer 2005), etc.

Reports on the influence of musical experience and practice on performance in dichotic listening tasks are controversial. Some studies found no influence for tonal sequences (Mazzucchi, Parma, & Cattelani, 1981; McRoberts & Sanders, 1992; Zatorre, 1979), chords, syllables, digits (Nelson, Wilson, & Kornhass, 2003), or timbre (Prior & Troup, 1988). On the other hand, it has been reported that musicians display REA for perception of melodies whereas LEA is found in non-musicians (Bever & Chiarello, 1974; Johnson, 1977; Larmande, Blanchard, Sintes, Belin, & Autret, 1984; Messerli, Pegna, & Sordet, 1995). Bever and Chiarello (1974) attributed this result to distinct ways of listening to musical structures: an analytic way in musicians (supported by the left hemisphere) and a holistic way in non-musicians (supported by the right hemisphere). Rather than a sharp distinction between musicians and non-musicians, later studies supported the idea of different analytic (local, or pitch- and interval-based) versus holistic (global, or melodic- and contour-based) processes. These can be usually invoked in both musicians and non-musicians by appropriate stimulation and instruction (for a review see Peretz & Morais, 1988).

In the present study we readdressed the question of how musical practice affects the hemispheric processing of auditory stimuli as indexed by dichotic listening performance. In particular, we were interested in the influence of musical experience on the processing of non-musical sounds. Therefore, in addition to simple two-tone sequences, we introduced consonant-vowel (CV) syllables and various environmental sounds that have not been studied in connection with musical experience so far. Previous studies suggested that musical training could affect the lateralisation of language functions. Hassler (1990) used dichotically presented words and reported the lateralisation of verbal processing towards the left hemisphere (right ear) to be decreased in male artists including musicians. In females, in contrast, an opposite pattern was seen—artistic education was associated with increased leftward hemispheric lateralisation We expected to obtain comparable results using CV syllables, although reliability of laterality assessment as derived from dichotic listening tests using words is lower than the reliability from tests that employ CV syllables (Voyer, 1998). On the other hand, Russell and Voyer (2004) have shown that dichotic listening to words and syllables can differ, with words yielding greater REA than syllables. This could mirror the fact that syllables lack a semantic dimension and allow the adoption of a nonverbal, acoustic strategy. Such an acoustic-based, nonverbal strategy could be strengthened by musical training. Therefore, a decrease in REA (or, equivalently, an increase in LEA) in both male and female musicians is predicted. Similar mechanisms are expected to play role in dichotic listening to environmental sounds. Besides increasing the recall accuracy, musical training might bias the processing towards acoustic-based rather than semantic-based mechanisms, which should be reflected by a stronger LEA in musicians than in non-musicians.

METHOD

Participants

A total of 60 (35 females, 25 males) undergraduates aged 18–26 years (mean = 21.4) participated in the study. All participants were right-handed (hand preference questionnaire: Bryden, 1982) and had no left-handed first-degree relatives. Participants had no history of neurological disorders or traumatic brain injury and reported normal hearing, which was controlled by a screening examination of hearing accuracy. This was performed using Home Audiometer software (version 1.7) at frequencies 250, 500, 1000, and 2000 Hz. The interaural threshold difference did not exceed 10 dB. The participants were divided into two groups:

1. "Musicians" (33 participants; 20 females, 13 males): individuals with active musical experience (playing an instrument in an ensemble or singing in choir for at least 3 years; all non-professionals).
2. "Non-musicians" (27 participants; 15 females, 12 males): individuals with no active musical experience.

The study was approved by a local ethical committee and was carried out in accordance with the declaration of Helsinki. All participants gave informed consent to participate in the study.

Auditory stimulation

For the purpose of this study two nonverbal dichotic listening tasks (environmental sounds and two-tone sequences) were developed by the first author (MŠ). In addition, we used a dichotic listening task with CV syllables (Jariabková, 1987). The stimuli were recorded on a CD and played from a Smarton SM-216 CD player via Sennheiser HD 475 supra-aural headphones (total harmonic distortion $< 0.7\%$) at a sound level of 75 dB. Channels were reversed in the middle of the testing procedure for all tasks.

Environmental sounds. Environmental sounds were used as stimuli (e.g., a woman's cough, footsteps, a falling lid, sawing wood, a crying baby, a man laughing, singing birds, a car starting, a dog barking, a door slamming). All sounds were recorded on a computer equipped with a 16-bit SoundBlaster Live sound card at a sampling rate of 44 kHz with 16-bit resolution. Duration of the stimuli was adjusted to 1.5 s. The stimuli were temporally aligned for simultaneous onset and offset in left and right channels (with 1 ms accuracy). They were normalised to equal loudness using RMS normalisation procedure, which is based on spectral sensitivity of the human ear. Stimuli were assigned into dichotic pairs according to their frequency spectrum and time course, which prevented very different (and hence easily discriminable) stimuli occurring within a dichotic pair. The task began with 12 trials of single-pair stimuli, which were introduced to familiarise the participants with this type of auditory stimulation. Consecutively, 32 trials with two dichotic pairs of environmental sounds were presented. Only performance with the double-pair stimuli was further analysed.

Two-tone sequences. There were three types of two-tone sequences: low–high, high–low, low–low. Low–high and high–low combinations formed the interval of a minor third. They were easy to discriminate by participants with no musical experience, as had been verified in pilot measurements. Square waves with fundamental frequencies 440 Hz (a1), 494 Hz (b1), 523 Hz (c2), and 587 Hz (d2) were used. The duration of each tone was 0.6 s and two tones were paired with no gap, forming a sequence lasting 1.2 s. Stimuli were aligned for simultaneous onset and offset in the left and right channel with 1 ms accuracy. Different sequences were presented to each ear and each combination of sequences was presented 14 times yielding a total possible score of 42 for each ear.

CV syllables. Six stop-consonant-vowel (CV) syllables "ba", "da", "ga", "ka", "pa", and "ta", pronounced by a female speaker, were used as stimuli. The syllables were paired randomly. Within a trial, homonymic syllables were allowed to occur in a single channel only. The dichotic test consisted of successive presentation of four trials with a single pair of syllables, four trials with two pairs of syllables, and four trials with three pairs of syllables. The task was repeated with the channels reversed, resulting in a total possible score of 48 for each ear.

Procedure

Participants were tested in an acoustically shielded room. The three tasks (environmental sounds, two-tone sequences, and CV syllables) were presented in a random order. A free recall paradigm of dichotic listening was used. Participants reported their answers orally (such as "footsteps", "man laughing", etc. in case of environmental sounds; "ascending [tones]", "descending [tones]", "the same [tones]" in case of two-tone sequences) and were recorded by the experimenter (MŠ). The participants did not report in which ear the stimuli were perceived. There was no time limit for the response.

Data analysis

Laterality index (LI) was calculated for each task and participants according to the formula: LI = (R–L)/(R + L), where "R" and "L" are numbers of correct responses delivered from the right and left ear respectively. A mixed-design analysis of variance (ANOVA) was calculated for each stimulus type (environmental sounds, two-tone sequences, and CV syllables) separately with a within-subject factor Ear (correct responses from the left ear, correct responses from the right ear) and between-subject factors Music (musicians, non-musicians) and Sex. For the CV syllables the number of CV pairs in the trial was considered an additional within-subject factor. Participants whose LI failed to fall into the interval ± 1.5 * interquartile range of the whole sample were regarded as outliers and were removed from the analysis (tone sequences: 3 subjects, environmental sounds: 0, CV syllables: 0).

RESULTS

In all three tasks (environmental sounds, tonal sequences, and CV syllables) we found a significant effect of the factor Ear. A left ear advantage (LEA) was observed in both musicians and non-musicians (Figures 1 and 2) for nonverbal tasks: environmental sounds [$F(1, 58) = 26.53$; $p < .0001$] and two-tone sequences [$F(1, 55) = 18.23$; $p < .001$]. For two-tone sequences, but not environmental sounds, the effect of factor Music was significant: a higher number of correct responses from both ears was delivered by musicians than non-musicians [$F(1, 55) = 13.74$; $p < .001$]. For both two-tone sequences and environmental sounds the Ear × Music interaction was not significant, i.e., musical experience did not influence ear preference for nonverbal stimuli.

CV syllables yielded a right ear advantage (REA) in both groups [factor Ear: $F(1, 58) = 70.28$; $p < .0001$], but a larger REA was found in non-musicians than in musicians [Ear × Music: $F(1, 58) = 7.11$; $p = .009$]. However, as shown in Figure 1 (upper right corner), the larger REA in non-musicians was attributed to males only [Ear × Music × Sex: $F(1, 58) = 5.78$; $p = .02$]. Performance and lateralisation in musicians and non-musicians

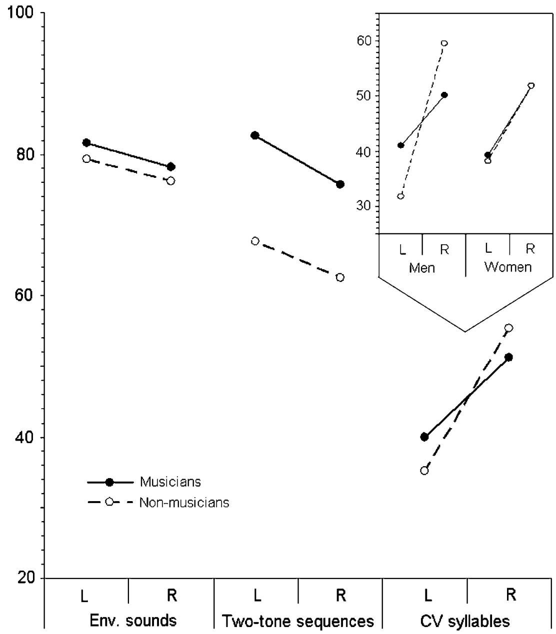

Figure 1. The mean performance of musicians (filled circles, solid lines) and non-musicians (open circles, dashed lines) in dichotic listening to environmental sounds, two-tone sequences, and CV syllables. The percentage of correct responses from the left and right ear is plotted. The inserted plot in the upper right corner displays the sex differences for CV syllables.

were not influenced by the number of CV pairs (1, 2, or 3) presented in the single trial.

A more detailed analysis of the dichotic performance revealed a substantial difference in performance between the tasks employing verbal and non-verbal stimuli. As can be seen in Figure 2, for CV syllables the number of correct responses from the right ear was negatively correlated with that from the left ear ($r = -.361$, $p < .01$). In contrast, for nonverbal tasks we found a positive correlation between the numbers of correct responses from the two ears (environmental sounds: $r = .866$, $p < .01$; two-tone sequences: $r = .755$, $p < .01$). This difference between the two types of stimuli was seen in both musicians and non-musicians, and in both sexes. Furthermore, we found differences in inter-individual variability of lateralisation among the three stimuli. Environmental sounds yielded substantially lower variability than two-tone sequences and CV syllables (see the histograms in Figure 2).

In addition, we explored associations in performance among the three types of stimuli. Lateralisation (expressed by the laterality index, see Method) as well as total number of correct responses were uncorrelated

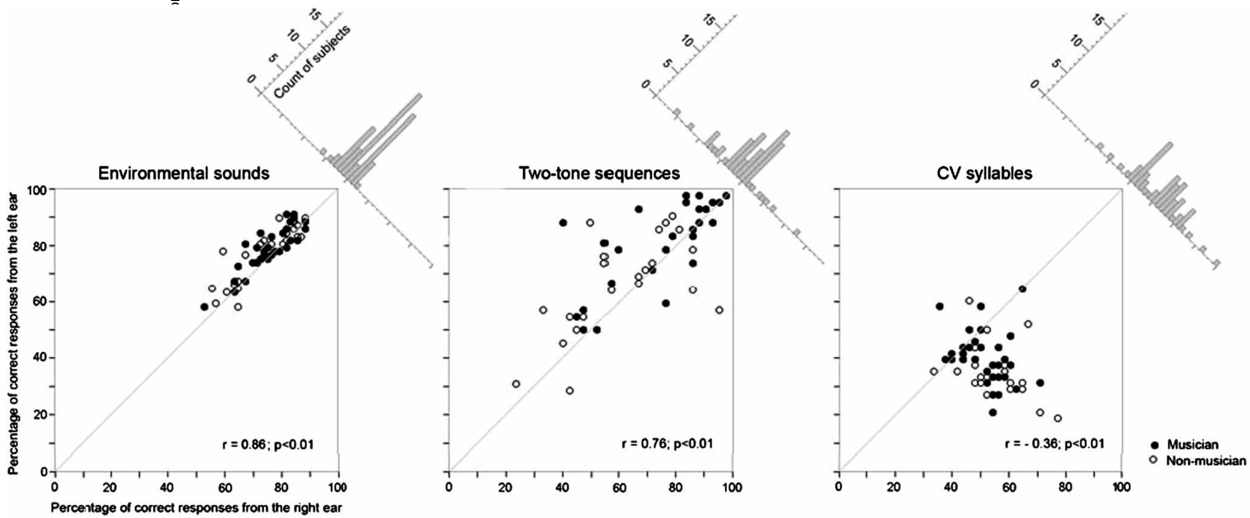

Figure 2. Association between the correct responses from the right and left ear respectively in musicians (filled circles) and non-musicians (open circles). Histograms depict the distribution of the R–L difference score among all participants.

between the three tasks (data not shown). This was true irrespective of musical experience and sex of the listeners.

DISCUSSION

Dichotically presented nonverbal stimuli yielded LEA whereas verbal stimuli yielded REA in both musicians and non-musicians. The influence of musical experience was found for two-tone sequences and CV syllables, but not environmental sounds. The effect of musical experience on dichotic listening to CV syllables was seen in males but not females.

In the task employing two-tone sequences the musicians were obviously able to benefit from their musical practice and delivered a higher number of correct responses than participants with no active musical experience. However, no difference in lateralisation between the two groups was found. These results seem to contrast with previous reports of REA for tone sequences in musicians and LEA in non-musicians (Bever & Chiarello, 1974; Johnson, 1977; Larmande et al., 1984). However, these studies employed more complex musical material such as excerpts from musical pieces or melodies consisting of several tones. Bever and Chiarello (1974) argued that REA in musicians was due to an interval-based (analytic or local) type of melody recognition connected with the left hemisphere, whereas LEA in non-musicians could be attributed to a contour-based (holistic or global) type of melody recognition supported by the right hemisphere. Our results do not contradict these arguments. The simple sequences used in our experiments could be discriminated solely from the global contour information. No exact interval recognition was required to solve the task successfully. Thus the higher ability of musicians to apply the analytical approach (and hence a different pattern of laterality) could not be demonstrated. Since males are more likely to adopt the analytical strategy than females are (Peretz & Morais, 1983), the absence of sex differences in laterality could have similar reasons. In addition, the task imposed low demand on other cognitive processes, such as attention or memory, that may be differently engaged in by musicians and non-musicians respectively (Peretz, Morais, & Bertelson, 1987). Our results (see especially Figure 2) suggest that, as for the simple two-tone sequences, there are sufficient unused processing resources in individuals without active musical experience. Musical practice probably enables participants to exploit the underlying processes more efficiently with no need for recruitment of additional cognitive mechanisms.

In musicians a lower REA was found for CV syllables in comparison to non-musicians but the entire difference was attributed to males. In other words, musical practice abolished sex difference in dichotic listening to CV syllables. The predicted decrease in REA was not found in female musicians. Neither did we observe the reversed effect of musical training—lower REA in males and higher REA in females—previously reported by Hassler (1990) using dichotically presented words. However, our results correspond well with structural imaging study of Lee, Chen, and Schlaug (2003) who reported that size of corpus callosum, a marker of interhemispheric connectivity, had been higher in male musicians than in male non-musicians and similar to females irrespective of musical experience. It has been repeatedly shown that the specialisation of the left hemisphere for language processing is higher in men than in women (Bryden, 1988; Hiscock, Inch, Jacek, Hiscock-Kalil, & Kalil, 1994; Voyer, 1996). Females typically outperform males in verbal abilities (for a review see, e.g., Kimura, 1996) so it is tempting to speculate that a certain degree of hemispheric asymmetry, such as found in females, might be optimal for language processing. Thus our results could be related to reports on positive influence of musical experience on verbal abilities (Hassler, 1990; Schlaug, Norton, Overy, & Winner, 2005). Although there was no association between the lateralisation and overall performance in the dichotic listening to CV syllables, such a relationship could occur in more demanding or complex verbal tasks. Further experiments focusing on the influence of musical competence on language processing should help to resolve this issue.

On the other hand, our findings do not necessarily imply an induction of structural changes in brain asymmetry by musical experience. Additional factors such as task difficulty, attention, and memory are known to play a role in dichotic listening (Bloch & Hellige, 1989; Hugdahl, 1995; Mondor & Bryden, 1991, 1992; Voyer & Flight, 2001b). Furthermore, it has been reported that sex differences could vary with the experimental paradigm and hence with the strategy employed to solve the dichotic listening task (Voyer & Flight, 2001a). Using the method of free recall we were not able to differentiate between the possible factors and to attribute the effects to specific mechanisms. The total percentage of correct responses indicates that CV task was more difficult to solve than the non-verbal tasks. High task difficulty increases the possibility that attention could be specifically allocated towards one of the ears in order to increase the success of the response. However, several factors indicate against a significant contribution of inappropriate attention allocation: (1) The participants were instructed explicitly to pay attention to both ears and to avoid attending to one of the ears only. (2) No feedback was provided to the participants, so that they were not able to monitor the success of their performance. (3) Degree of lateralisation did not correlate with the number of correct responses. (4) No difference in lateralisation was observed with two-tone sequences between musicians and non-musicians, despite the fact that non-musicians delivered a significantly lower number of correct responses, so that the task was more difficult for them.

In addition, it is possible that specific patterns of lateralisation could be present in individuals who aim for a musical training. Norton et al. (2005) found a positive correlation between perceptual skills in music and phonemic awareness in children starting musical training. Whether these differences are accompanied by specific lateralisation shifts is not clear yet. Nevertheless, our results indicate that specific differences in laterality of auditory processing occur in individuals with active musical experience.

The overall recall of CV syllables was similar among the participants. The relatively constant level of the overall performance indicates rather limited free resources for the processing of phonological material. This might reflect high demands of language processing, which is expected to heavily exploit the capacity of the underlying substrate. In contrast, lateralisation for CV syllables was considerably inter-individually variable (cf. Segalowitz, 1986; Voyer, 1998). We note at this point that the validity of laterality assessments derived from verbal dichotic listening tests has been directly confirmed by the amytal technique (Strauss, Gaddes, & Wada, 1987) as well as functional neuroimaging (Hund-Georgiadis, Lex, Friederici, & von Cramon, 2002). On the one hand, the inter-individual variability of lateralisation could indicate differences in the strategy adopted in order to solve the task (Russell & Voyer, 2004; Voyer & Flight, 2001b). On the other hand, Morton and Rafto (2006) reported that variability of lateralisation found in dichotic listening to CV syllables reflected differences in interconnection between the hemispheres via corpus callosum. This finding is also supported by evidence that the interference between dichotic materials occurs at cortical rather than subcortical level and mostly relies on callosal connections (Di Stefano, Salvadori, Fiaschi, & Viti, 1998; Jäncke 2002).

Musical experience had no influence on the dichotic listening to environmental sounds. We had expected that musicians would be able to engage different mechanisms and strategies and hence outperform non-musicians. In addition, in participants with musical training higher lateralisation towards the left ear corresponding to higher recruitment of acoustic (non-semantic) mechanisms could be expected. However, the invariable processing of such sounds is also indicated by the low inter-individual variability of lateralisation. An evolutionary perspective could indicate a possible explanation (cf. Corballis, Funnell, & Gazzaniga, 2000). Perception of environmental sounds, in contrast to verbal and tonal stimuli, was of vital importance during phylogenesis. Consequently, processing of environmental sounds underwent a strong evolutionary pressure and stabilisation. We could only speculate that musical training could affect the processing of these sounds, if used in different (e.g., musical) context.

We found no correlation in the laterality among the three types of stimuli tested. Moreover, musical experience and sex had no influence on this relationship. On first consideration, such a result might be unexpected given that the majority of participants showed LEA for two-tone sequences and environmental sounds and REA with CV syllables. However, previous reports have already stated the independence of lateralisation for different auditory stimuli (Boucher & Bryden, 1997; Bryden, 1982). Probably, independent mechanisms are engaged in the processing of the three types of sounds. Our results, which suggest a non-uniform specific impact of individual experience on auditory processing, provide support to such an idea.

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