ROLE OF FAMILIARITY IN AUDITORY DISCRIMINATION OF MUSICAL INSTRUMENT: A LATERALITY STUDY

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ABSTRACT

Normal subjects were presented with dichotic pairs of sounds differing in pitch-timbre combination. Their task was to detect a fixed target sound that occurred randomly but equally often in the right and the left ear in two-thirds of the trials. Half the subjects performed this task with sounds produced by familiar natural instruments (violin, flute, guitar and drum), and the other subjects performed the same task but with the sounds played backwards, hence being less recognizable. Subjects were quicker and more accurate in discriminating forwards than backwards played sounds, hence exhibiting sensitivity to familiarity with musical instrument sounds. Recourse to this knowledge was, however, not associated to a shift in laterality. For both familiar and unfamiliar sounds, a robust left-ear advantage (LEA) was observed.

INTRODUCTION

Piano and flute are easy to discriminate and to identify, even when they are playing a single note at the same pitch. Despite this apparent simplicity, instrument timbre identification requires consideration of multiple acoustic cues. Spectral content (i.e. the number and amplitude of frequency components, referred to as harmonics) and temporal profile, of which the onset portion (i.e. the attack) is most distinctive, are considered as most determinant of instruments identification. All these acoustic parameters appear to be analyzed in the right auditory cortex (Samson and Zatorre, 1994; Auzou et al., 1995). This right-hemisphere specialization for musical timbre represents one of the most robust laterality findings in the literature. Converging evidence has been gathered in a large variety of neuropsychological contexts, including patients after unilateral excision of the temporal lobe (Milner, 1962; Samson and Zatorre, 1994) or after unilateral lesion due to vascular stroke (Chobor and Brown, 1987; Mazzucchi et al., 1982), and normal subjects by measuring metabolic brain responses (Mazziotta et al., 1982), EEG recordings (Auzou et al., 1995) and ear-asymmetries (e.g. Rastatter and Gallaher, 1982; see Peretz, 1985, for a more extensive review).

Given the few auditory devices that can be unambiguously attributed to the functioning of the right cerebral hemisphere, defining the optimal conditions of this right-hemisphere involvement is a worthwhile empirical entreprise. In the present study, we examined one such condition, namely that created by the existence of stored representations for musical timbre. It has been known for a

long time that familiarity with the characteristic waveform of an instrument contributes to the process of timbre identification. For example, a piano tone played backwards considerably reduces its recognizability, in spite of the fact that most acoustical properties remain unchanged (Berger, 1964). The involvement of such type of memory-associative knowledge, assumed to be represented in the long term stored representation of the familiar instrument timbres, may recruit more of the left-hemisphere structures and hence set up a limit to the right-hemispheric predominance in timbre discrimination. Following Goldberg and Costa (1981), there would be a right-to-left shift in hemisphere superiority as a function of increased familiarity with the material to be processed.

If these premisses were correct, then all prior studies which made use of synthetic sounds, by being less familiar, should have observed a right hemisphere superiority whereas those previous studies which employed natural stimuli should have obtained a left hemisphere superiority. The literature is largely inconsistent with this assumption since right-hemisphere superiorities have been observed for both types of sounds (e.g. Samson and Zatorre, 1994, for synthetic sounds, and Rastatter and Gallaher, 1982, for natural sounds). It may, however, be premature to reject the notion that familiarity with the sounds can induce a shift to the left hemisphere. The main reason is that the processing of familiar and unfamiliar musical timbres has not been directly compared in the same neuropsychological study.

The goal of the present study was to fulfill this gap in assessing the role of familiarity with sounds that are acoustically highly similar and with task parameters that are held constant. To this aim, we used the sounds produced by natural familiar instruments (e.g. guitar, flute, violin and drum) in one condition (the natural condition) and their time reversal (i.e. played backwards) in another condition (the reverse condition). Backward presentation allows for the balancing of the acoustic complexity of the stimuli while keeping familiarity distinct. In both conditions, stimuli were presented dichotically to normal subjects. Their task was to detect as quickly as possible a particular instrument target that occurred equally often but randomly in the left and the right ear. To ensure discriminability of the target under dichotic presentation, and thus reliability of response time measurements, the different instruments produced a different pitch. We predicted a left-ear advantage (LEA), which is indicative of a right-hemisphere superiority, for the discrimination of the unfamiliar timbre-pitch combinations in the reverse condition. Assuming that the natural condition loads on a further memory-associative stage which engages the left hemisphere, a shift in laterality towards a right-ear advantage (REA) can be expected in that condition.

Materials and Method

Subjects

Two groups of 12 university students (six males and six females) each, between the age of 18 and 38, participated in the present study. All were right-handed (according to Oldfield's handedness questionnaire), nonmusicians (i.e. having less than four years of musical practice as part of the regular school program) having normal audiometry (for pure tones from 125 Hz to 8000 Hz).

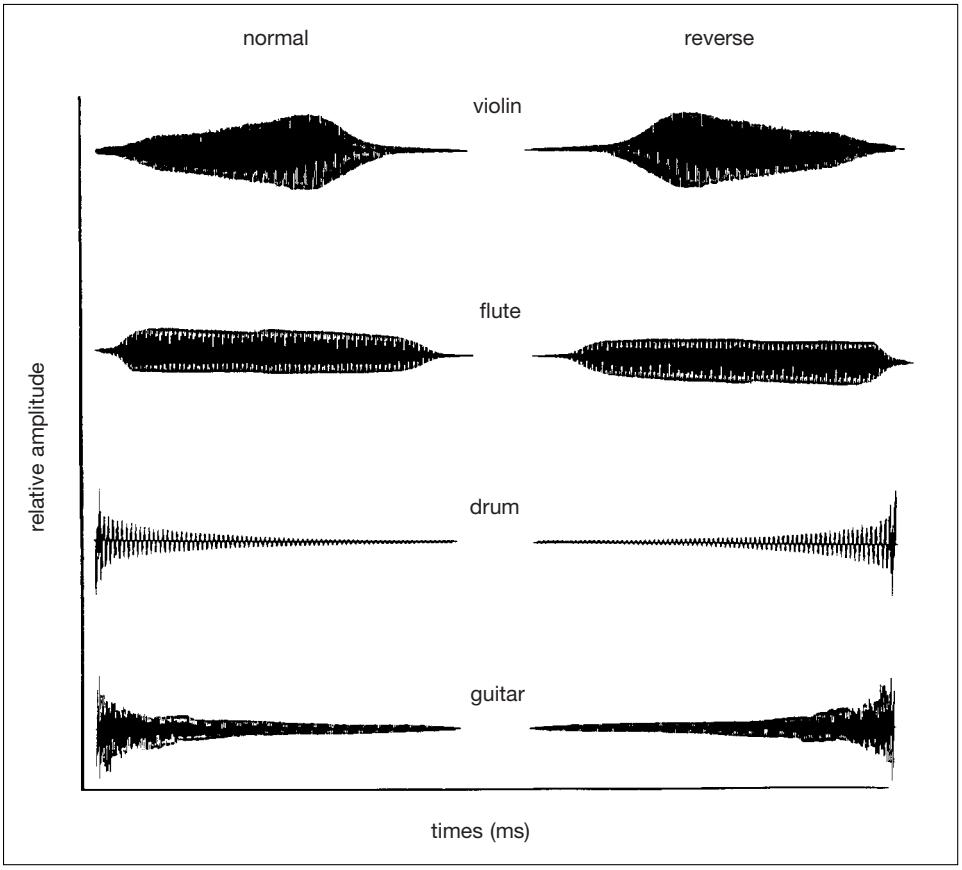

Fig. 1 – *Envelopes of the four instrument sounds that were used in the natural condition (left panel) and in the reverse condition (right panel).*

Stimuli

There were two conditions: The natural condition and the reverse condition. Stimuli differed only by their onset to offset unfolding, which was usual in the natural condition and reversed in time in the reverse condition. The natural sounds were produced by a classical guitar (playing G4), a flute (A4), a drum (F4) and a violin (bowed at C3) and digitized onto the hard disk of a Macintosh II-FX computer for editing. The sounds were adjusted so as to last 600 ms each and to have the same output intensity as measured by a sound level meter located at the output of the headphones. The envelope of each sound is represented in Figure 1. The attack of the drum and the guitar were short (with 1.9 ms and 5.9 ms, respectively), moderate for the flute (60 ms) and slow for the violin (100 ms). In the reverse condition, the envelope of these four natural sounds were reversed in time using the Sound Designer II facilities. Thus, pitch, loudness, spectral content and duration of the sounds remained the same, whereas the dynamics were slightly modified (see Figure 1) with much slower attacks (with 550, 450, 230, 100 ms, for the reverse waveform of drum, guitar, violin and flute, respectively). Pilot subjects easily recognized all the natural sounds and failed to recognize their backward versions to the notable exception of the backward flute sound which remained somewhat recognizable.

Stimuli were recorded and aligned in pairs, one on each channel, so as to have simultaneous onset. All possible pairings were used, thus yielding six different dichotic

pairs. The experiment consisted of 216 such pairs (6 blocks of 36 trials each). Each trial started with a warning signal (a beep), which was followed by a dichotic pair. Each trial was separated by a 4 s interval. The target corresponded to the violin in both conditions. The target randomly occurred on one channel in the third of the trials so that the target was present in two-thirds of the dichotic trials and absent in the remaining third.

Apparatus and Procedure

The experimental session started with the handedness questionnaire, followed by the musical education questionnaire and the audiometric test. Subjects were assigned randomly but in equal number to the natural or to the reverse condition. The subjects sat in a soundproof room and read instructions for the timbre detection task: On presentation of each dichotic pair, participants were asked to indicate as quickly as possible whether the designated target was present or not, with a toggle switch. The toggle had to be moved up for "yes" and down for "no" for half the subjects, and in the reverse direction for the other half. Half the subjects started to respond with their right hand and half with their left hand; hand of response changed every block. The headphone (Uher W710) position was counterbalanced across subjects.

Before the dichotic test, participants familiarized themselves with the sounds. Each sound was presented binaurally three times and the target, 15 times. After this binaural presentation phase, the subject was familiarized with the task on 15 further practice trials under dichotic presentation. The presentation and familiarization phase were repeated once if the subject did not obtain at least 70% of correct responses. Four subjects in the reverse condition failed to reach this criterion on a second hearing and thus were discarded and replaced. At the end of the session, subjects were asked to comment about the strategy that they had used to perform the task.

The apparata were different in the two conditions[1]. The natural condition was delivered to the subjects via an analogical tape recorded (REVOX B77) which was connected to a personal computer (IBM compatible AT-286) running a program that recorded response times and errors. The reverse condition was presented on a digital tape recorder (TASCAM DA-30) which was connected to a Macintosh Classic II computer running a program that recorded time and accuracy of the responses. Each experiment lasted about 25 minutes.

RESULTS

In order to assess laterality effects on accuracy measures, an ANOVA was computed on mean correct raw scores with Conditions (natural vs. reverse) and Sex (female vs. male) as between-subjects variables, and Ear of input (right vs. left) and Hand of response (right vs. left) as within-subjects variables. This analysis revealed an interaction between Condition, Sex and Ear of input ($F = 6.4$; d.f. = 1, 20; $p < .05$). This interaction was due to the presence of an Ear by Sex interaction in the reverse condition, with $F = 6.4$, d.f. = 1, 10; $p < .05$. In the latter condition, male subjects exhibited a significant LEA ($t = 2.904$; d.f. = 4; $p < .05$) whereas female subjects did not. There was no such effects in the natural condition where performance was close to ceiling, with no subject scoring below 95% correct. In fact, both conditions were performed at a high level of accuracy, with 98% and 90% of correct responses in the natural and reverse condition, respectively. This high level of performance does not

[1] This change in equipment was motivated by the need to use high-quality sounds; digital recording was, however, only available for the testing of the reverse condition. This should have no incidence on laterality, although it may well have improved subjects' discriminability in the reverse condition.

favor the emergence of laterality effects. In such context, response time is the most sensitive dependent variable.

A similar ANOVA was computed on the median response times for correctly detected targets, taking the same factors as that performed on accuracy measures into consideration. As can be seen in Figure 2, the natural condition was found to be far easier than the reverse condition, with 388 ms and 781 ms mean response times, respectively ($F = 36.6$; d.f. = 1, 20; $p < .005$). Moreover, a reliable Ear effect emerged ($F = 14.07$; d.f. = 1, 20; $p < .001$), which did not depend on Condition (Ear by Condition, $F < 1$). Ten out of 12 subjects exhibited a LEA in the natural condition and nine out of 12 subjects did so in the reverse condition (both $p < .05$ by a sign test). Sex and Hand of response did not have any significant effects nor were found to interact with other factors.

In order to assess the stability of the observed LEA across trials, an ANOVA was computed on the correct median response time as a function of Condition, Ear of input and Block (block 1 to block 6). This analysis yielded a significant interaction between Ear and Block ($F = 2.06$; d.f. = 5, 110; $p < .05$). For each Block, the LEA reached significance (all $p < .05$ by uilateral t tests) except for Block 6, where the LEA was not significant.

Further analyses were conducted on response time in order to assess whether or not some sound combinations were more discriminable and/or lateralized. In the natural condition, the violin-flute pairing gave rise to the quicker responses ($F = 7.7$; d.f. = 2, 22; $p < 0.005$). This was not accompanied by any difference in laterality pattern; the LEA remained reliable across all instrument combinations. In the reverse condition, no particular pattern emerged significantly.

Discussion

As predicted, discrimination of backwards sounds gives rise to a robust LEA. This is consistent with the notion that such discrimination primarily taps an acoustic stage that is lateralized to the right hemisphere. Adding meaningfulness to the sounds, by presenting the sounds of familiar musical instruments in their normal format, did not affect the laterality pattern. In the latter condition, a reliable LEA was observed as well. Since stimuli and task were identical in the two conditions to the exception of the sound format, the results suggest that either 1) subjects did not rely on their prior knowledge of the instrument timbre in the natural condition or 2) the memory-associative stage of timbre processing is lateralized to the same hemisphere as the one which subserves their acoustic analysis. Each point will be discussed in turn.

In discriminating familiar sounds (i.e. presented in their standard format), subjects may have used the same acoustic cues as those extracted in their reversed formats. Reliance on similar acoustic properties in the two conditions is indeed very likely. However, we further hypothesized that associative memories would be involved when subjects detect the familiar sounds. Such a contribution of long term stored representations of what a musical instrument sounds like should confer the familiar condition an advantage over the unfamiliar condition. This advantage was clearly present in the data. Subjects were more accurate and much

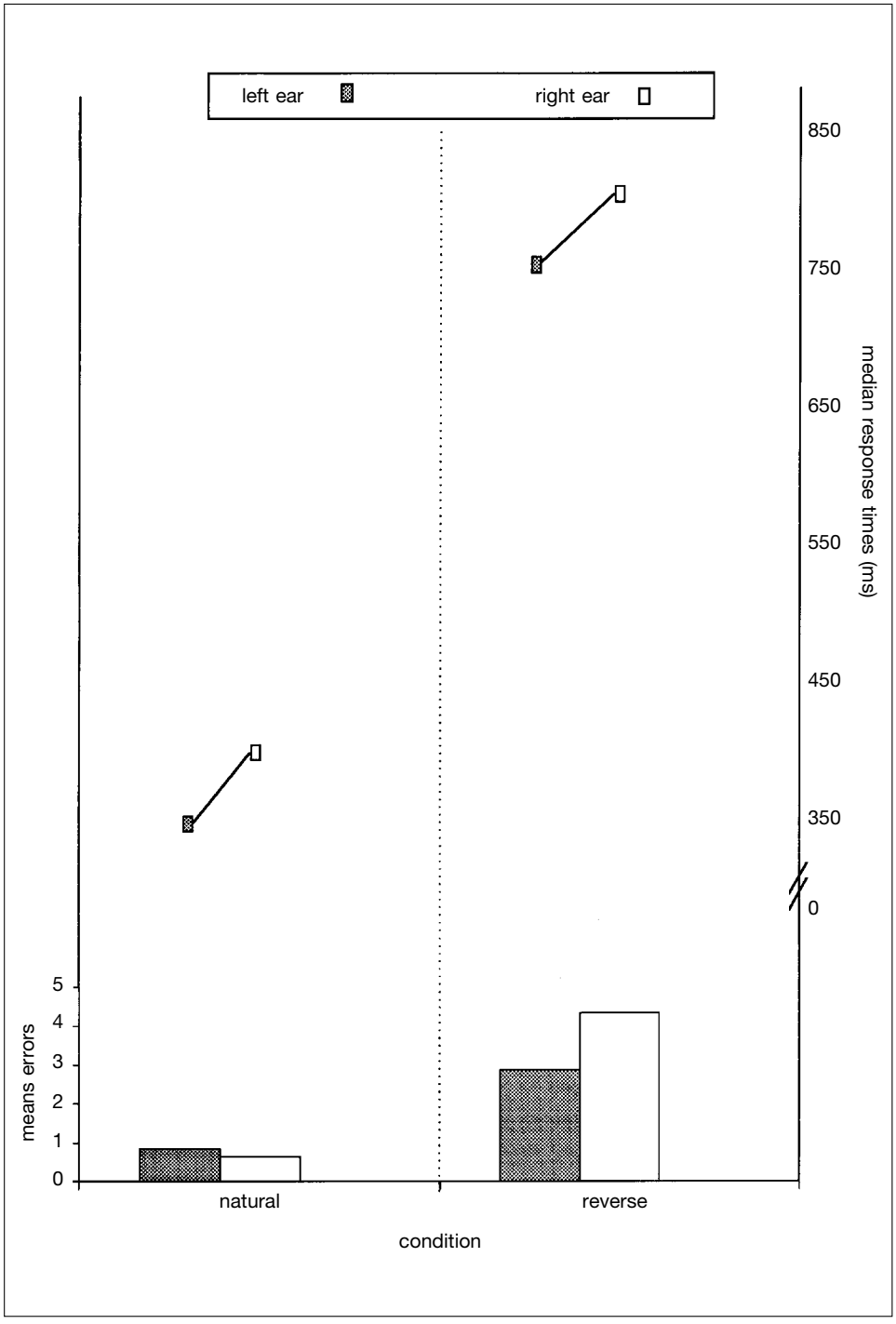

Fig. 2 – *Mean error rate (bars) and median correct response times (lines) for each ear in each condition.*

quicker to detect a familiar target instrument than its backwards version. Thus, the present results extend to a discrimination task previous findings showing that backwards presentation is detrimental to musical timbre recognition (Berger, 1964).

In both conditions, the tones to be discriminated differed in pitch as well as in timbre. Thus, to perform the task, the subjects may have relied on pitch which, in complex sounds, is processed in the right hemisphere (e.g. Sidtis, 1980; Paquette et al., 1996). However, then prior familiarity with the sounds should not play any role since the pitch differences were identical in the natural and the reverse condition. Yet, there was an effect of familiarity. Moreover, it should be mentioned that even when instruments produce the same pitch (let say, A4), pitch differences are not completely eliminated. Acoustical correlates of timbre affect pitch perception (Moore et al., 1992; Patterson, 1990; Singh and Hirsh, 1992). In principle then, pitch differences can account for most, if not all, studies that have been conducted on timbre discrimination. In the present situation, when subjects were specifically queried at the end of testing about the presence of pitch differences, they reported that they did not perceive them. Finally, if pitch differences affected the discrimination of the tones in the present experiment, then such influences should be apparent. That is, more errors and longer response times should be found in trials where the dichotic sounds are closer in pitch (e.g. the violin-flute pair) than in trials where the sounds are more distant in pitch (e.g. the violin-guitar pair). Instead, when a significant difference occurred in discriminability, it was found in favor of the violin-flute pair which was the easiest. Thus, the pitch explanation can not account for the results.

It is, however, likely that pitch and timbre were perceived as an integrated entity (i.e. as an indivisible whole). According to several recent studies, pitch does not appear perfectly dissociable from timbre (Crowder, 1989; Melara and Marks, 1990; Krumhansl and Iverson, 1992). Pitt (1994) has, however, demonstrated that timbre variations affected nonmusicians' judgments of pitch more than the reverse. He reasoned that, for nonmusicians, timbre is probably a more salient dimension than pitch because the former is generally more informative about environmental events and these listeners have not been trained to analyze pitch closely. This account fits with the present findings since subjects were nonmusicians and clearly showed evidence of sensitivity to timbre factors and little, if any, consideration of pitch discrepancies.

Thus, the present results suggest that both the perceptual analysis and the use of associative memories for timbre take place in the right hemisphere. Such a conclusion does not entail that these two processing stages are undissociable and implemented in identical brain circuitries. The acoustical analysis and memory activation may still be performed by neurally adjacent but distinct networks. This latter possibility is supported by the finding that discrimination and identification of the same instrument sounds are dissociable after brain damage (Peretz et al., 1994).

In summary, the present study indicates that discrimination of familiar and unfamiliar instrument sounds is lateralized predominantly to the right-hemisphere structures. Thus, the results do not support the notion that familiarity with the musical instrument may increase left-hemispheric involvement. On the positive

side, the present study provides new conditions of auditory complex pattern lateralization for which prior familiarity and verbal encoding appears to have little impact. The situation appears to be ideally suited to elicit robust LEAs, a rarely achieved condition in nonverbal auditory discrimination.

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