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The neural bases underlying pitch processing difficulties

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ABSTRACT

Normal listeners are often surprisingly poor at processing pitch changes. The neural bases of this difficulty were explored using magnetoencephalography (MEG) by comparing participants who obtained poor thresholds on a pitch-direction task with those who obtained good thresholds. Source-space projected data revealed that during an active listening task, the poor threshold group displayed greater activity in the left auditory cortical region when determining the direction of small pitch glides, whereas there was no difference in the good threshold group. In a passive listening task, a mismatch response (MMNm) was identified for pitch-glide direction deviants, with a tendency to be smaller in the poor listeners. The results imply that the difficulties in pitch processing are already apparent during automatic sound processing, and furthermore suggest that left hemisphere auditory regions are used by these listeners to consciously determine the direction of a pitch change. This is in line with evidence that the left hemisphere has a poor frequency resolution, and implies that normal listeners may use the sub-optimal hemisphere to process pitch changes.

Introduction

Research on auditory processing has largely focused on groups of listeners who perform well on auditory tasks. It is common practise to exclude listeners who do not perform optimally (e.g. Demany, 1985; Demany and Semal, 2002), and few studies have addressed the question of why some listeners perform so much worse than others. Many studies on pitch processing have employed the pitch direction task, but it has recently been shown that around 15% of listeners have great difficulty on this task (Semal and Demany, 2006). Semal and Demany (2006) showed that this difficulty was not due to deficits in detecting the presence of pitch changes *per se*, and also showed that it could not be due to a problem with the concepts of rising or falling pitch changes, as participants were able to perform the task accurately for large pitch changes.

Several studies have examined the neural bases of pitch-direction determination, which may help towards understanding the difficulty found in some listeners. Studies in animals have demonstrated that it is possible to train certain species (e.g. Mongolian gerbils, rats, macaque monkeys) to determine the direction of a pitch change (Wetzel et al., 1998a; Syka et al., 2003; Brosch et al., 2004), and have shown that this is dependent upon an intact auditory cortex (Ohl et al., 1999; Harrington et al., 2001), predominantly in the right hemisphere (Wetzel et al., 1998b; Syka et al., 2003). In humans, a neuropsychological study linked performance on the pitch direction task with the right Heschl's gyrus, showing that epilepsy patients who had brain surgery to remove this cortical region exhibited deficits in pitch direction determination, whereas this was not the case for patients whose surgery encroached upon left hemisphere regions or right-hemisphere temporal regions away from Heschl's gyrus (Johnsrude et al., 2000). Recent functional imaging studies also support the role of the right auditory cortex in pitch direction determination (Behne et al., 2005; Brechmann and Scheich, 2005). For instance, Brechmann and Scheich (2005) found stronger activation in certain regions of the right auditory cortex for a pitch-direction categorisation task compared to a task based on the sound duration. These studies all suggest that difficulties in pitch-direction processing relate to neural processes in right auditory regions.

Studies using EEG and MEG have provided evidence that the direction of a pitch change can be encoded automatically, when attention is directed away from the sounds. For example, Pardo and Sams (1993) presented participants with a series of pitch glides with the same direction and a roving centre frequency, that were interspersed with occasional 'deviant' sounds that glided in the opposite direction. They found that a mismatch negativity (MMN) component was elicited in response to the deviant sounds, which reflects the automatic comparison of current auditory input with memory traces formed by previous auditory input (Naatanen et al., 2007). Other studies have shown that a MMN component is also elicited for pairs of discrete tones that violate an otherwise regular feature of ascending or descending

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pitch (Saarinen et al., 1992; Paavilainen et al., 1995, 1999). These findings show that the direction of a pitch change can be encoded in the absence of attention to the sounds, and suggest that difficulties in pitch-direction determination may be apparent at a pre-attentive level of sound processing.

The present study aims to determine the neural bases of difficulties in pitch direction processing by comparing MEG recordings obtained in two groups of individuals: those who obtain high (poor) thresholds on a pitch direction determination task and those who obtain low (good) thresholds. The first section investigates group differences during an active listening task, where participants are asked to decide whether the direction of a pitch glide matches the direction of an arrow (visual stimulus) that is presented after a short delay. It is hypothesised that group differences will be apparent during task performance in the region of the auditory cortices, particularly in the right hemisphere, in line with previous studies (e.g. Johnsrude et al., 2000; Behne et al., 2005; Brechmann and Scheich, 2005). The second section addresses whether group differences can be observed in the absence of attention towards the sounds by determining whether a MMNm component (magnetic counterpart of the mismatch negativity) is elicited in response to sounds that contain a 'deviant' pitch direction. It is hypothesised that group differences will also be apparent for this automatic measure of pitch-direction processing, again in the region of the auditory cortices, particularly in the right hemisphere. Analyses will adopt a source montage approach, with dipoles in the region of the auditory cortices, in order to approximate activity in these regions and examine hemisphere differences. This approach has been successfully adopted in many previous MEG studies (e.g. Schneider et al. 2005; Fujioka et al., 2006; Gutschalk et al., 2007; Okamoto et al., 2007).

Materials and methods

Participants

28 right-handed participants were recruited, aged 19 to 47. All reported normal hearing and no history of neurological or psychiatric disease. Behavioural tests were administered to determine perceptual thresholds for recognising the direction of a gliding pitch change, and also for detecting the presence of a gliding pitch change. For both tests, the sounds were of 500 ms duration, gated with 10 ms amplitude ramps, and were either steady pure tones, or linear pitch glides, consisting of a 100 ms constant pitch (pure tone), followed by a 300 ms pitch ramp (glide), and ending with a 100 ms constant pitch. For the pitch-direction task, participants were presented with one upward-gliding sound and one downward-gliding sound, both of the same magnitude. These were presented in a random order and were separated by a 500 ms gap. The task was to decide whether the first or the second sound glided upwards in pitch. For the pitch-change detection task, participants were presented with one steady pure tone and one sound that glided in pitch, which was randomly an upward or a downward glide. Again the two sounds were presented in a random order and separated by 500 ms. The task was to decide whether the first or the second sound contained a change in pitch. For both tasks, the comparison sounds were centred on a common frequency, which varied randomly from trial to trial to one of seven values, from 513 Hz to 595 Hz. Both tests followed an adaptive tracking procedure in order to determine the perceptual threshold. The initial magnitude of the pitch glide was 1.5 semitones, and this varied thereafter in steps of 0.1 semitones, using an adaptive tracking procedure where one incorrect response led to an increase in the glide magnitude, and two consecutive correct responses led to a decrease in the glide magnitude. There were a total of 60 trials per condition, although the length was increased by 30 trials if the adaptive track had not reached a stable plateau. Thresholds were taken as the mean glide magnitude for the last six changes in the direction of the track. All tests were carried out in a quiet side-room in the laboratory, and the sounds were presented over headphones at a comfortable level.

Two groups of seven individuals were selected; those who obtained the lowest thresholds on the pitch direction task, and those who obtained the highest. The low threshold group, referred to here as the 'good threshold group', obtained a mean threshold of 0.16 semitones (range 0.08 to 0.25 semitones), and the high threshold group, referred to as the 'poor threshold group', obtained a mean threshold of 1.91 semitones (range 1.4 to 2.5 semitones). For the pitch-change detection task, the group differences were smaller, with a mean threshold of 0.22 semitones (range 0.05 to 0.45) for the good threshold group, and a mean threshold of 0.48 semitones (range 0.27 to 0.85) for the poor threshold group. The groups did not differ markedly in terms of age (on average 29 years for the good threshold group and 25 years for the poor threshold group) or gender (with 2 female participants in the good threshold group and 3 in the poor threshold group). However it was noted that the good threshold group participants had received more musical training than the poor threshold group, with an average of 6.4 years learning to play a musical instrument (range 2 to 12 years) compared to an average of one year for the poor threshold group (range 0 to 2 years), although there were no professional musicians.

All of the selected participants were administered the scale subtest of the Montreal battery of musical evaluation (Peretz et al., 2003) in order to determine whether they might have the music perception disorder congenital amusia (Ayotte et al., 2002). This was an important consideration, given that individuals with this disorder show significantly higher thresholds for pitch direction determination (Foxton et al., 2004). In this test, participants are asked to decide whether two melodies are identical or different. The differences occur in one note of the melody, which is played out of key. Scores on this test were found to lie in the normal range for all of the participants, ranging from 26/30 to 30/30 in both groups (mean 28.9 for the good threshold group; mean 28.3 for the poor threshold group), thus demonstrating that they did not have a music perception disorder. A *t*-test showed that there was no significant group difference on this measure ($p = 0.43$).

MEG recordings and stimuli

The recordings were carried out using a whole-head, 275-channel MEG system (CTF-275 by VSM Medtech Inc., Vancouver, Canada) with continuous sampling at a rate of 600 Hz, and a 0–150 Hz filter bandwidth. Head position was determined with coils fixated at the nasion and the preauricular points and this was checked at the beginning and end of the recordings in order to ensure that the head movements did not exceed 0.5 cm. The participants were seated upright in the sound-attenuating, magnetically shielded recording room, and listened to the sounds presented binaurally through air-conducting tubes with foam eartips. As the amplitude of the sounds was found to be distorted for the gliding pitch changes following presentation through the tubes, the amplitude pattern of the original sounds was modified to ensure that the final sounds were of constant amplitude. Prior to each recording, thresholds for sound detection were determined, and the level was adjusted so that the sounds were presented at a level of 45 dB sensation level.

Protocol A

This section investigated the processing of pitch direction during an active listening task. Participants were presented with a single pitch glide that was either small (1.2 semitones) or large (9 semitones). The task was to decide whether the direction of the pitch glide matched that of an arrow, presented after a short delay. Based on the thresholds for pitch-direction determination, it was anticipated that the good threshold group would perform well on the task for both the