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Use of time differences in normal hearing – cortical processing of promontorial stimuli

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Abstract

To test the hypothesis that ability to discriminate small duration differences is positively correlated with activity in the right temporal lobe, we used positron emission tomography in six normally hearing subjects, stimulated via the promontory in a procedure that mimics the auditory nerve stimulation with a cochlear implant. Stimulus consisted of electrical bursts, and tasks included gap detection and temporal difference limen (TDL). TDL is a measure of discriminatory processing of sound duration in cochlear implant candidates, demonstrated to predict outcome. Good speech perception after cochlear implantation is associated with activity in right temporal areas.

Although perceived variably by the subjects, the stimulus itself activated bilateral secondary somatosensory cortex, suggesting differential stimulation of multiple sensory modalities. Only TDL raised blood flow in both posterior middle temporal gyri (MTG) and the right prefrontal cortex. As the right posterior MTG is known to be active during duration discrimination of different modalities and in the perception of words containing manipulated phonemes, we conclude that recruitment of this part of the right hemisphere is important to the comprehension of speech containing mostly temporal cues. The study shows that stimulus-induced activation reflects the goal of the task rather than the nature of the stimulus.

Keywords: PET; Duration discrimination; Promontory; Stimulation; Temporal analysis; Speech perception; Somatosensory cortex

1. Introduction

Temporal information is fundamentally important to the analysis of speech. This study used simple non-verbal stimuli to examine the brain mechanisms involved in temporal resolution and analysis of duration of segmented sounds. This analysis is particularly relevant to the perception of spoken language (Shannon et al., 1995). Electrical stimulation of the promontory is used to predict the ability of a cochlear implant (CI) prosthesis to alleviate sensory deafness. In this test, executed prior to the planned CI, an electrical current of low voltage and frequency is applied to the promontory (basal turn of cochlea) where it stimulates the inner ear. An auditory sensation of the stimulus is believed to demonstrate the responsiveness of auditory neurons (House and Brackmann, 1974) and hence to predict the probable success of the planned implantation. However, the exact nature of the correlation between the promontory test result and the underlying neuronal competence is unknown (Smith and Simmons, 1983), and the significance of a negative test is controversial (Luxford, 1989; Scao et al., 1993; Schmidt et al., 2003). Many centers have limited their use of this test to subjects with

Abbreviations: BA, Brodmann area; CI, cochlear implant; rCBF, regional cerebral blood flow; DR, dynamic range; GAP, gap detection; MAL, maximum acceptable loudness; MCL, most comfortable level; MR, magnetic resonance; PET, positron emission tomography; TDL, temporal difference limen; TL, threshold level

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severe ossificating labyrinthitis, or a history of trauma or retrocochlear surgery (Gantz et al., 1993).

Several studies nevertheless show that the part of promontory testing known as the temporal difference limen (TDL), performed to determine a patient's temporal processing ability, is of predictive value (Black et al., 1987; Waltzman et al., 1990; van Dijk et al., 1999). Also gap detection has been linked to postimplantation open-set speech recognition ability, although more weakly (Blamey et al., 1992; Muchnik et al., 1994). Because temporal coding is sufficient for speech comprehension (Cohen et al., 1993; Knauth et al., 1994; Shannon et al., 1995), a priori it is not surprising that temporal parsing in the auditory pathway affects implant performance.

Electrophysiological recordings, functional imaging, and lesion studies in humans, all show a right hemisphere bias for temporal processing. They also reveal that transmission between the auditory cortices and the frontal cortex is sufficient for higher-order temporal perception, i.e., the perception of continuous temporal modulation of sounds (Brunia and Damen, 1988; Griffiths et al., 2000; Rao et al., 2001). In a recent study, we demonstrated that right temporal activation (posterior and anterior) is correlated with the ability temporally to parse transmitted phonemes in cochlear implant users relying primarily on temporal cues (Mortensen et al., submitted). However, to identify pre-operative predictors of postoperative results, it is potentially important to combine electrical evaluation of the auditory system with functional neuroimaging (Scao et al., 1993; Truy, 1999).

To test the hypothesis that the pre-operative ability to involve the right temporal region is correlated with good speech perception after cochlear implantation, we used PET to map the neural mechanisms of the left and right hemisphere language areas that mediate temporal judgments in six normally hearing volunteers. Additionally, we wanted to know whether electrical stimulation in the vicinity of the cochlea is auditory or somatosensory, as the target of cochlear stimulation is uncertain (Truy et al., 1995; Schmidt et al., 2003). Specifically, we tested whether a right hemisphere lateralisation is induced by the temporal difference limen task. As perception of duration difference also relies on representations stored in working memory (Gibbon et al., 1984), we predicted that the right prefrontal cortex is involved in the execution of this task (Cohen et al., 1997; Smith and Jonides, 1999; Rao et al., 2001).

2. Materials and methods

2.1. Subjects

Six healthy right-handed normally hearing volunteers (two men and four women aged 31–52 years, mean 41.2 years) gave written informed consent to the study approved by the County Aarhus Research Ethics Committee. The subjects were included if they could perform the temporal tasks irrespective of the quality/nature of their perception of the stimulus. The volunteers had no history of neurological or psychiatric disorders.

2.2. Promontory testing

We stimulated the promontory with the Nucleus® Promontory Stimulator unit (model Z10012, Cochlear Corporation, Melbourne, Australia) by advancing a fine needle electrode through the posterior–inferior quadrant of the tympanic membrane onto the promontory (basal turn of the cochlea) approximately halfway between the umbo and the annulus.

The tympanic membrane was anesthetised with lidocain/prilocain (Emla®) applied topically for an hour before the test. The electrode was held in place by a foam earplug and the ground electrode was placed on the left antebrachium.

Subjects were placed supine on the scanner bed. The most comfortable level (MCL) was established before tomography: stimulation was initiated at 0 μA, using an electrically isolated constant-current square wave stimulus of 100 Hz, with a burst duration of 500 ms and a switch rate of 1 Hz. The current was slowly increased until the patient "heard" or "felt" the stimulus. Threshold was determined as the lowest current at which the subjects indicated that they could perceive the stimulus. Maximum acceptable loudness (MAL) was determined by increasing the current until the stimulation was no longer comfortable. MCL was just below MAL. Also prior to tomography gap detection and temporal difference limen were tested. The prescan data are listed in Table 1.

2.3. Temporal tasks

Promontory testing included two temporal processing tests, the temporal difference limen (TDL) and gap detection.

Temporal processing has two primary categories, *temporal integration* and *temporal resolution*. Temporal integration studies how increasing the duration of a signal makes it easier to detect. Temporal resolution or temporal acuity consider how fast the ear is, e.g., by

Table 1
Subject data

Subject	Sex	Age	TL (μA)	MAL (μA)	DR	GAP	TDL	Hearing percept
1	F	47	310	590	5.6	10	10	Yes
2	M	37	310	650	6.4	50	10	No (vibrotactile)
3	M	35	450	830	5.3	10	50	Questionable
4	F	31	51	120	7.4	50	50	No (vibrotactile)
5	F	52	240	552	7.2	50	30	Yes
6	F	45	120	230	5.7	50	20	Questionable