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The relationship between stream segregation and frequency discrimination in normally hearing and hearing-impaired subjects

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Abstract

We examined the relationship between the fission boundary (FB) at which a sequence of pure tones alternating between two frequencies cannot be heard as two separate streams and the frequency difference limen (FDL), using normally hearing subjects and subjects with cochlear hearing loss. The stimuli used in the two tasks were as similar as possible in duration and inter-tone interval. The frequency range examined was 250–8000 Hz for the normally hearing subjects and 250–2000 Hz for the hearing-impaired subjects. For normally hearing subjects, the FBs were almost invariant with frequency when expressed as ERB_N values; the mean FB was about 0.4 ERB_N. The FDLs, also expressed as ERB_N values, increased for frequencies above 2000 Hz. The ratio FB/FDL was roughly constant at 7–9 in the frequency region 250–2000 Hz, but decreased for higher frequencies, reaching about 1 at 8000 Hz. For the hearing-impaired subjects, FB/FDL ratios varied over a large range (1–40), and were not systematically related to the amount of hearing loss. These results suggest that the FB is not determined solely by the discriminability of successive tones.

Keywords: Stream segregation; Frequency discrimination; Hearing impairment; Perceptual grouping

1. Introduction

Hearing-impaired people often complain of difficulty in understanding speech in the presence of background sounds; for reviews, see Plomp (1994) and Moore (1998). The major factors contributing to this difficulty remain unclear. Reduced audibility probably plays a role, but even when sounds are amplified so as to restore audibility, the difficulty usually remains. It has been proposed that reduced frequency selectivity plays an important role, and simulations of reduced frequency selectivity support this proposal (Baer and Moore, 1993, 1994; Nejime and Moore, 1997; ter Keurs et al., 1992, 1993). However, it seems likely that reduced frequency selectivity is not the only supra-threshold factor involved.

One possible factor is connected with the ability to assign rapid sequences of sounds to their appropriate sources, in other words, to form perceptual streams. When we listen to rapid sequences of sounds, such as those that occur in speech or music, sounds with components falling in similar frequency ranges tend to be grouped together (i.e., perceived as if they come from a single source – this is called fusion or coherence), whereas sounds with components in different frequency ranges tend to be perceived as different streams (as coming from more than one source – this is called fission or

Abbreviations: ΔE, difference in ERB_N number; ERB_N, equivalent rectangular bandwidth of the auditory filter; FB, fission boundary; FDL, frequency difference limen

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segregation) (Bregman, 1990; Moore and Gockel, 2002; van Noorden, 1975). For intermediate frequency separations between successive tones in a rapid sequence, the percept is ambiguous; either fission or fusion may be heard, depending on the attentional set of the subject and the instructions given. If the frequency separation is larger than a critical value, called the temporal coherence boundary, two streams are *always* heard. If the frequency separation is less than a (different) critical value, called the fission boundary (FB), then a single stream is *always* heard. The frequency separation at the FB is affected only slightly by the number of tones per second, while the frequency separation at the temporal coherence boundary increases markedly as the number of tones per second increases (van Noorden, 1971, 1975). In this paper, we focus on the FB for two reasons. Firstly, it tends to be more stable, both within and across subjects, than the temporal coherence boundary. Secondly, the FB is likely to be related to the *limits* of the ability to "parse" a rapid sequence of sounds into two or more streams.

Rose and Moore (1997) showed that FBs were larger than normal in some, but not all, subjects with substantial cochlear hearing loss. They argued that their subjects would probably all have had reduced frequency selectivity (the reduction was confirmed for some subjects, using the notched-noise method), so the failure to find enlarged FBs for all subjects indicated that the FB was not determined solely by peripheral frequency selectivity, as assumed in some models of auditory stream formation (Beauvois and Meddis, 1996; Hartmann and Johnson, 1991; McCabe and Denham, 1997).

Mackersie et al. (2001) showed that the ability of hearing-impaired subjects to identify a target sentence in the presence of a competing sentence was correlated with the FB; the smaller the FB the better was the intelligibility of the target speech. However, no relationship was found between speech intelligibility and frequency selectivity at 1 kHz, measured using the notched-noise method (Patterson and Moore, 1986). Mackersie et al. concluded "Results suggest that the abilities to perceptually separate pitch patterns and separate sentences spoken simultaneously by different talkers are mediated by the same underlying perceptual and/or cognitive factors." It is important therefore, to examine the factors that might lead to increased FBs in some hearing-impaired subjects.

Rose and Moore (1997) suggested that one factor influencing the FB might be the clarity of the pitch sensations evoked by the tones. It may be that the pitches of successive tones need to be clearly different for fission to be heard (Moore and Gockel, 2002). If the pitches of the tones are unclear, this may lead to larger-than-normal FBs. It is known that the frequency discrimination of sinusoids is worse than normal in people with cochlear hearing loss (Hall and Wood, 1984; Moore and Peters, 1992; Nelson and Freyman, 1986); for reviews, see Moore (1998) and Moore and Carlyon (2005). Several of the hearing-impaired subjects tested by Rose and Moore reported that the pitches of the tones were unclear or "fuzzy" when they fell in certain frequency ranges. Frequency discrimination abilities show marked variation across hearing-impaired subjects, and are not well correlated with estimates of the auditory filter bandwidth (Moore and Peters, 1992; Tyler et al., 1983). This may be the case because frequency discrimination (and the perception of pitch) depends on the timing of neural impulses (phase locking) as well as on the distribution of activity along the basilar membrane. Variations in frequency discrimination ability across subjects could well account for some of the individual differences in the FB found by Rose and Moore.

In the present study, we examined the relationship between the FB and frequency discrimination in subjects with normal hearing and subjects with cochlear hearing loss. For normally hearing subjects, the FB is approximately invariant with frequency when expressed in units of ERB_N, the equivalent rectangular bandwidth of the auditory filter, as determined at moderate sound levels using young normally hearing subjects (Glasberg and Moore, 1990; Moore, 2003); the value of the FB is about 0.4 ERB_N (Rose and Moore, 1997, 2000). The value of the frequency difference limen (FDL) for normally hearing subjects, when measured using a pulsed-tones discrimination task (where the subject has to identify which of two successive tones is higher in frequency), is *not* invariant with frequency when expressed in ERB_N units (Moore, 1974; Sek and Moore, 1995). At first sight, this appears to suggest that the FB is not closely related to the FDL. However, the FB is usually measured using brief tones ($\sim$100 ms) with very short silent intervals between successive tones ($\sim$20 ms). FDLs measured under similar conditions might be almost invariant with frequency when expressed in ERB_N units, just as is the case for thresholds for detecting frequency modulation (Sek and Moore, 1995). In the present paper, the stimuli used for measuring the FDLs were chosen to be as similar as possible to those used for measuring the FBs. This was done to allow a more rigorous assessment of the idea that the FB is determined by the discriminability of the successive tones.

2. Method

All procedures described here were approved by the "Cambridge Research Ethics Committee".

2.1. Subjects and choice of test level

Five normally hearing and six hearing-impaired subjects were tested. Absolute thresholds for the latter are