Frequency and Location Discrimination: Which is Faster?

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SUMMARY

It is debatable whether frequency information is processed faster than location information or vice versa. In a Go/Nogo task, Scharf, Possamaï, and Bonnel (personal communication) found evidence suggesting that frequency discrimination is faster than location discrimination. In contrast, Schröger and Wolff (1997) presented evidence suggesting that location discrimination is faster. To choose between these two contradictory predictions, we designed an experiment in which we carefully equated discriminability (in terms of just noticable differences or jnds) and the type of discrimination task. In 10 subjects the 0.90 jnd (stimulus difference required for 90% correct) was first determined in a weighted up-down adaptive procedure (two-interval forced choice), separately for frequency and lateralization (based on interaural time difference). Next, in reaction time (RT) measurements, for each subject, stimuli were separated either by these jnd-values ("difficult" condition) or by 5 times these values ("easy" condition). In three different RT tasks subjects had to discriminate frequency and location (blocked presentation). The mean RTs ranged from 314 to 559 ms and were about the same for location and frequency discrimination in all three tasks. These means as well as the cumulative RT distributions did not indicate that one feature was discriminated significantly faster than the other feature at a behavioral level in any of the tasks. Accordingly, neither of our predictions is confirmed. It seems that both auditory features are available to cognitive discrimination operations at about the same time.

INTRODUCTION

Sound is normally perceived as a limited number of discrete auditory objects such as a ringing phone or the voice of a particular person. These percepts have to be constructed from the multitude of cues contained in the basic stimulus features, notably frequency, duration, and intensity. How these basic features are processed by the human brain is a central issue in cognitive neuroscience (e.g. Näätänen & Winkler, in press). It is known that the features are represented in anatomically separate regions even in the cortex (e.g. Giard et al., 1995). However, it is not known just when these representations of the various features become available for cognitive operations such as the attentional selection among sounds or their behavioral discrimination. It is, for example, unclear whether frequency information can be discriminated faster than location information or the other way around. Since our auditory system is organized tonotopically from the cochlea through the cortex (e.g., Romani, Williamson, & Kaufman, 1982), frequency discrimination would be expected to be faster than location discrimination. This hypothesis is supported by a recent study by Scharf, Possamaï, and Bonnel (personal communication). They found that subjects responded faster when the task was to respond to a tone at one frequency and not at another than when the task was to respond to a noise burst from one direction but not from another direction. In contrast, two previous studies reported shorter RTs in location discrimination than in frequency discrimination (Näätänen et al., 1980; Schröger & Wolff, 1997).

However, all these studies failed to equate carefully the discriminability for location and frequency. Moreover, they can not be directly compared since they used different tasks, and it might be that the superiority of one dimension over the other depends on the type of task. To determine which of the two features is discriminated faster, we designed a behavioral study without these shortcomings. We equated the discriminability in the frequency and location dimensions in terms of individual just noticable differences (jnds) and we measured RT in the same three tasks requiring frequency or location discrimination. In addition, since an RT difference between the two dimensions might depend on the difficulty of the discrimination, we measured RT when the discrimination was easy and when it was difficult.

METHODS

Subjects: Twelve paid volunteers participated in the experiment. Two of them had to be excluded, owing to poor performance in one or more of the tasks. Thus ten subjects (7 females, 3 males), aged 20-29 years (mean of 23.2 years) remained in the sample. One subject was left-handed, and the rest were right-handed.

Stimuli and apparatus: The subjects were seated in a dimly lit, sound attenuated chamber. Response buttons were placed under their left and right index fingers. All sounds were pure tones with a duration of 50 ms and a 5-ms rise/fall time; they were delivered binaurally via headphones at approximately 70 dB SPL. Sound frequencies between 600 and 750 Hz were used. Perceived location, i.e. lateralization, was based on interaural time differences (ITD, which included both onset and phase differences) in the range of 0 to 600 µs for a 600-Hz pure tone. For the measurement of jnds a two-interval-forced-choice (2IFC) task was used. The two intervals were separated by 1,350 ms; a trial started 1,400 ms after the subject's button-press response. RTs were measured in a Go/Nogo task and also in a two alternative forced choice (2AFC) task.

Procedure: In the first part of an experimental session, the jnds for frequency and location discrimination were measured in two separate blocks in random order. An adaptive "weighted up-down," 2IFC procedure (Kaernbach, 1991) was used to determine the jnd required for 90% correct. Subjects were presented with two stimuli in random order, one at 600 Hz with an ITD of 0 µs (which is normally heard in the middle of the head) and the other at either a different frequency or with a different ITD. They pressed a button to indicate whether the second tone was higher or lower (frequency block) than the first tone or more to the left or to the right (lateralization block). A block started with a maximum difference of 30 Hz (standard at 600 Hz, comparison at 630 Hz) or of 120 µs (standard 0 µs, comparison 120 µs). The task became more difficult in steps of 1 Hz or 4 µs following a correct response or easier in steps of 9 Hz or 36 µs following an incorrect response. This procedure was followed for 16 reversals (defined as a correct response following an incorrect response or vice versa); the mean value of the last 12 reversals represents the 90% jnd. In the second part of the experimental session, subjects performed three different tasks at two levels of difficulty, separately for frequency and location discrimination for a total of 12 experimental blocks performed in randomized order. In two Oddball-Go/Nogo tasks with targets presented on 20% or on 80% of the trials, subjects had to press a button as soon as they heard a target, which was either a higher tone or one towards the right in a series of standard sounds (600 Hz, 0 µs ITD). In the 2AFC task subjects had to discriminate between low or middle and high or right signals, each of which was presented on 50% of the trials in random order. They indicated their choice by pressing either a left or a right button. All tasks were performed twice: once at a "difficult" level, when the high or right sounds were separated from the low or middle standard tone (600 Hz, 0 µs ITD) by each subject's individual 90% jnd-value or second at an "easy" level when the tones were separated by 5 times the 90% jnd-value. The 20:80 Go/Nogo blocks consisted of 300 trials, the 80:20 Go/Nogo blocks of 75, and the 2AFC blocks of 120 trials. Subjects were told to respond as quickly and accurately as possible.

Data analysis: Responses sooner than 100 ms and later than 1,200 ms after stimulus onset were excluded from further analysis.

RTs measured in the 2AFC task to sounds in the middle and on the right were pooled together, and a repeated measures analysis of variance (ANOVA) -- with the factors task (20:80 vs. 80:20 Go/Nogo vs. 2AFC), domain (frequency vs. location), and difficulty ("difficult" vs. "easy" condition) -- was performed. We used PR (hit rate minus false-alarm rate) to analyze performance instead of d' since several subjects showed false alarm rates of zero in some conditions. The PR-values measured in the Go/Nogo tasks were analyzed with an ANOVA including the factors target frequency (20% vs 80% targets), domain, and difficulty. The hit rates obtained in the 2AFC task were analyzed with an ANOVA including domain and difficulty level as factors. For the analysis of the cumulative frequency distributions (CFDs) of the RTs the 10% fastest and 10% slowest responses were removed for each subject for each combination of the factors task and difficulty. Then, "running" t-tests of the CFD for frequency against the CFD for location discrimination were performed for the three tasks at the two levels of difficulty.

RESULTS

The frequency differences needed for 90% correct responses in the 2IFC frequency discrimination task ranged from 5 to 25 Hz with an average of 14.9 Hz. The ITDs needed for 90% correct in the location discrimination task ranged from 32 to 88 µs with an average of 68 µs. (These jnds are larger than would be expected from data in the literature and probably reflect the inexperience of the subjects.)

Mean RTs (Table 1) ranged from 314 to 559 ms. RTs differed significantly among the three tasks (F(2,18)=12.82, GGeps=.895, p=.001). Subjects were fastest in the 80:20 Go/Nogo condition (370 ms), average in the 2AFC condition (424 ms), and slowest in the 20:80 Go/Nogo condition (478 ms); moreover, t-tests of all three differences were significant. Also RTs were faster in the "easy" conditions (360 ms) than in the "difficult" conditions (487 ms, F(1,9)=74.29, p<.001). The RT difference between frequency discrimination (427 ms) and location discrimination (421 ms) was not significant.

TABLE 1: RTs [ms] in the three tasks for the "easy" and for the "difficult" frequency and location discriminations.

	Task					
	20:80 Go/Nogo		80:20 Go/Nogo		2AFC	
Discrimi-nation	**"Diffi-cult"**	**"Easy"**	**"Diffi-cult"**	**"Easy"**	**"Diffi-cult"**	**"Easy"**
Frequency	558.5	387.7	422.8	332.1	508.6	352.4
Location	544.4	419.8	410.7	313.7	479.4	355.0

The average PR-value in the Go/Nogo tasks was 84%. The detection rate was higher for infrequent targets (88%) than for frequent targets (80%, F(1,9)=7.12, p=.026) and higher in the "easy" condition (92%) than in the "difficult" condition (76%, F(1,9)=19.54, p=.002). The average hit rate in the 2AFC task was 93%. It was higher in the "easy" (99%) than in the "difficult" condition (88%, F(1,9)=27.05, p=.001). Again, the difference in performance between frequency and location discrimination was significant neither in the Go/Nogo tasks (PR-values 86% vs. 82%) nor in the 2AFC task (hit rate 94% vs. 93%). The d' (computed from the data pool from all subjects) was slightly higher for frequency (3.0) than for location (2.7) discrimination.

Since none of the statistical tests revealed any significant differences between the speed of discrimination of frequency and location, the CFDs of the RTs were examined. The running t-tests of the CFD for frequency discrimination against the CFD for location discrimination in each of the conditions gave no indication that one type of discrimination is faster than the other.

DISCUSSION

The present study does not support either of the two opposing predictions; location discrimination and frequency discrimination seem to be about equally fast. Thus the differences in their speed of processing, reported in previous studies (Näätänen et al., 1980; Scharf et al., in prep.; Schröger & Wolff, 1997), may have reflected easier discriminability in the faster dimension. Since we found no difference in three tasks, which were similar to those in the previous studies, differences in the tasks used in those studies can not explain their discrepant outcomes.

Nonetheless, no difference in the speed of behavioral discrimination does not mean that there are no differences at earlier stages of processing, stages which may be tapped by electrophysiological measures. Indeed, Schröger and Wolff (1997) found such a difference in a study based on event-related potentials. The latency of the mismatch negativity (MMN), generated by the brain´s automatic detection of a sound change (see Näätänen, 1992), was shorter to a location change than to a frequency change. However, Deouell and Bentin (1998), after adjusting the magnitude of deviance between dimensions individually so that the detection rates were similar both across dimensions (within subjects) and across subjects (within dimensions), found no latency differences between location MMN and frequency MMN.

One may ask why frequency is not discriminated faster although it is encoded already at the cochlear level whereas the direction of a sound must be computed from interaural time and level differences. One explanation might be that behavioral discrimination requires not only the encoding of the relevant feature of the immediate sound into a neural representation but requires also a representation of the standard sound in memory, after which a comparison between these two representations becomes possible. In other words, we are suggesting that discrimination implicates memory and memory comparison in addition to the basic encoding of stimulus features.

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