TWO FOR ONE : DISCRIMINABILITY FUNCTIONS CAN PRODUCE BOTH MASKING AND FIXED-SIGNAL FUNCTIONS.

Daniel Shepherd[1] and Michael J. Hautus[2]

[1] School of Psychology, The Auckland University of Technology, Auckland, New Zealand
[2] Department of Psychology, the University of Auckland, Auckland, New Zealand

Abstract

Auditory level discrimination tasks require observers to judge which of two stimuli, X *or* $X+\Delta X$*, has the greater level. Four observers participated in a two-alternative forced-choice task with two 10-ms bursts of 1000-Hz sinusoids of level* X *and* $X+\Delta X$*. Sinusoids were presented in quiet. Five discriminability functions were collected, each based on seven values of* ΔX*. From these functions, masking and fixed-signal functions can be constructed by extracting the relevant information from each of the five discriminability functions. By comparing the masking and fixed-signal functions it should be possible that the units problem in audition can be brought to finality.*

In a difference discrimination task a pedestal of level X and that pedestal plus an increment, ΔX, are compared by an observer who reports which of X or $X+\Delta X$ they judge to be of greater magnitude. A popular measure of quantifying performance in a difference discrimination task is the difference threshold. Psychometric functions, in the context of difference discrimination termed *discriminabilty functions*, are commonly used to estimate difference thresholds. When a set of discriminability functions are generated, where each function represents a different level of the pedestal, X, a masking function plotting the difference threshold as a function of pedestal level can be constructed. The difference threshold, and its conceptual opposite representing similarity, the point of subjective equality, are not, however, the only measures to be extracted from discriminability functions. Across a range of functions a “fixed-signal” can be predefined, for example, the quantity of ΔX corresponding to 20% of the absolute threshold. A function plotting percentage correct as a function of pedestal level for a fixed-signal we call the *fixed-signal function*.

A series of discriminability functions can give rise to both masking and fixed-signal functions. It is a given that, for a value of X, a point on the masking function will be related to a point on the fixed-signal function. The form of the relationship is, of course, governed by the form of the discriminabilty function fitted to the data, and we are currently developing a function that will allow fixed-signal functions to be predicted from masking functions and vice versa.

An application of the relationship between the masking and fixed-signal functions was proposed by Shepherd and Hautus (2005) with reference to the *units problem in audition* (McGill and Teich, 1989). The auditory system can potentially respond to one of several physical characteristics of an incoming waveform when processing information relating to loudness. The candidates: pressure, energy, power, and intensity, are proportional to one another and hence it is not possible to choose amongst them using conventional psychophysical procedures. The units problem is of significance on account of negative masking, a phenomenon in which the masking function exhibits a substantial nonlinearity for pedestal levels bracketing absolute threshold, but differentially depending on unit selection.

We have argued elsewhere (Shepherd and Hautus, 2005) that the relationship between the masking function and the fixed-signal function can be used to find a solution to the units problem when circathreshold pedestal levels are employed.

The objective of this study is to construct a series of circathreshold discriminabilty functions and regress on to them a theoretical model of the form

$$p(c) = a\Phi(X)^b \qquad (1)$$

where *a* is a scalar and *b* determines the slope (or shape) of the function. It is our intent to express data in terms of either pressure (*p*) or intensity (*I*), and for each unit's set of discriminability functions both masking functions and fixed-signal functions will be constructed, contrasted, and interpreted in relation to the units problem.

Method

Observers

Four Observers, three males (MH=40; DS=33; IW=29) and one female (BM=25) participated in the experiment. Audiometric testing failed to expose any hearing loss between 500 and 8000 hertz. Observers BM and IW received a monetary incentive to participate.

Stimuli and Apparatus

1000-Hz sinusoids, 10 ms in duration, were constructed with 1-ms rise-and-fall times ($\cos^2$). LabVIEW 6.1, installed on a Pentium III personal computer, manufactured the sinusoids digitally (44.1-kHz sampling rate) and routed them to two externally mounted TDT PA5 attenuators, also controlled by LabVIEW via USB, through an inboard National Instruments digital-to-analogue converter (PCI-6052E). Following attenuation the sinusoids were transmitted to the headphone buffer (TDT HB7) and from there to an earpiece (Telephonics, TDH-49P cradled in an MX41/AR cushion). For the duration of an experimental block the observer was seated in a sound attenuating chamber (Amplaid Model E) in front of a response keyboard and a bank of three LEDs. All four observers received experimental stimuli monaurally through their left ears.

Procedure

A two-interval forced-choice (2-IFC) adaptive procedure to determine absolute thresholds was initially undertaken to allow pedestal levels to be normalised with respect to observer sensitivity (i.e., sensation level). Absolute thresholds were taken as the average threshold across ten blocks of trials. Each block consisted of 15 turnarounds determined by a three-down, one-up adaptive regime. Stepsize was initially 3 dB, changing to 1 dB after the first three turnarounds. The absolute threshold for a block was calculated as the average of the last twelve turnarounds.

Seven-point discriminability functions were generated for the following pedestal levels: -8, -4, 0, 4, and 8 dB SL. The procedure was a simple 2-IFC task in which one of the observation intervals was randomly assigned the pedestal (p=0.5) and the remaining interval the pedestal-plus-signal. A pilot study, aided by reference to the literature, guided the range of increment values for the circathreshold pedestal levels. The temporal sequence of events constituting an experimental trial was as follows: 1) a warning light consisting of a 500 ms illumination of an LED; 2) Observation interval one, which coincided with a 100-ms LED flash; 3) An interstimulus interval of 500 ms; 4) observation interval two, also coinciding with a 100-ms LED flash; 5) an interminable response interval and, contingent on response; 6) a feedback interval via one of two LED flashes. Across an experimental block the pedestal level was held constant while the increment levels were distributed randomly across the 105 trials constituting a block. The order of pedestal levels in the twenty blocks of trials was likewise randomised.

Results

Absolute thresholds for each observer were as follows: MH=15.15; BM=22.7; DS=15.42; IW=21.86 dB SPL. These estimates are in agreement with previously reported ranges from studies using similar stimulus parameters (Garner, 1947). Two sets of five discriminability functions were generated: a set each for stimuli presented in units of intensity (i.e., $\Delta I/I$) or pressure (i.e., $\Delta p/p$). Theoretical functions in the form of Equation 1. were then regressed onto the data and the best-fitting parameters a and b derived. These best-fitting parameters afforded the estimation of both the difference threshold and the percentage correct score for a fixed value of ΔX. Figure 1 shows two discriminability functions (where X=0 dB SL) for observer BM in terms of intensity (left) and pressure (right). Each point is based upon 90 trials, and each five point function is based on 450 trials.

The next stage of analysis will involve the construction of masking functions and fixed-signal functions. The behaviour of audiometric data about an observer's absolute threshold has long been known to differ qualitatively to data obtained in the suprathreshold range (Green and Sewall, 1962). Specifically, suprathreshold masking functions exhibit the linearity characteristic of Weber's law, whilst difference thresholds measured in the subthreshold region possess a nonlinearity (Laming, 1986) of extent constrained by unit selection. This pattern is likewise reflected in the fixed-signal function, and it is expected that its relationship to the masking function will yield insight into the units problem.

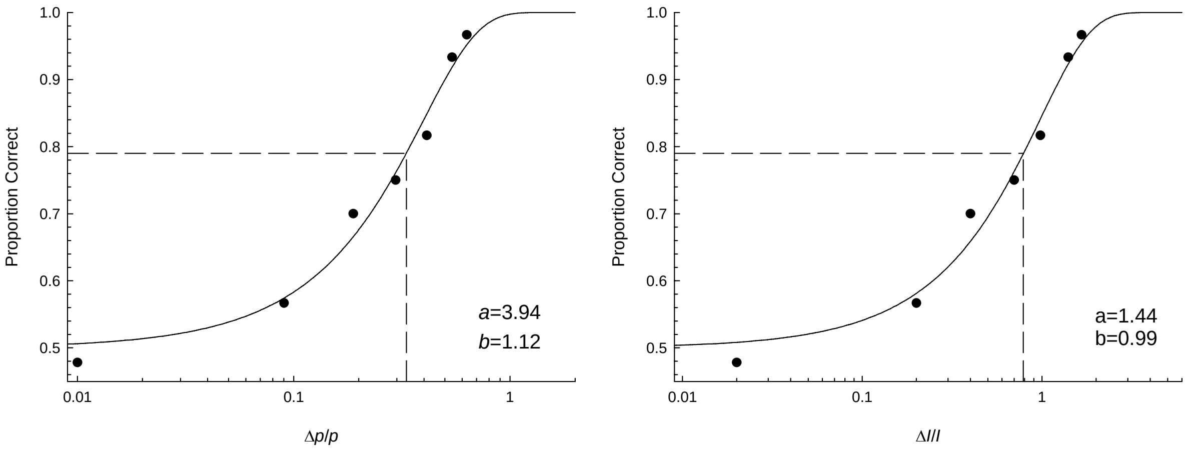

Fig. 1. Discriminability functions for data expressed in units of pressure (left) or intensity (right). The dashed lines represent a 79% correct difference threshold, and a and b are from Equation 1. Data are from observer BM for a 0 dB SL pedestal.

Discussion

The units problem has bedeviled auditory psychophysicists for the best part of fifty years. Advocates for both pressure (e.g., Laming, 1986) and intensity (e.g., Moore *et. al.*, 1999) have emerged, though the possibility that the auditory system may very well utilize both forms of information contingent upon the stimulus context should likewise be entertained (Ward, 2005).

Upon full and final analysis of the data we anticipate one of three outcomes:

i) Consistent with previous data (Shepherd and Hautus, 2005) the masking and fixed-signal functions will be consistent for stimuli expressed in units of pressure but not intensity.

ii) Only in terms of intensity, but not pressure, will there be a consistent relationship between the masking and fixed-signal functions.

iii) The masking and fixed-signal functions will be consistent irrespective of unit selection.

Note that finding i) and ii) above constitute convincing evidence towards a solution to the units problem. Outcome three, the least expected result given prior research findings (e.g., Pfafflin and Mathews, 1962; Hanna *et al.*, 1986) will not afford any conclusion as to whether the auditory system is operating on intensity of pressure information. Thus, whatever the outcome, the data will further illuminate the units problem and generate further questions regarding the auditory system's mode of operation.

Acknowledgments

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