Some considerations on the use of adaptive methods for estimating interaural-delay thresholds

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This letter makes recommendations on the use of adaptive psychophysics in binaural tasks involving the detection of interaural delays. Specifically, a logarithmic transformation of the stimulus dimension is recommended. The bases for this transform are explained. Monte Carlo simulations and data from human observers show efficient tracking of threshold. © *1995 Acoustical Society of America.*

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INTRODUCTION

The use of adaptive psychophysical techniques in binaural hearing has been limited. In a recent paper, Trahiotis *et al.* (1990) outlined some reservations which have frequently been expressed on using these techniques in binaural hearing, and showed, despite these concerns, a successful use of the Levitt (1971) up–down method in a masking-level-difference (MLD) task. The current letter makes recommendations on using adaptive psychophysics in binaural tasks involving the detection of interaural time differences (ITD). Of the few studies which have used adaptive tracking of ITD thresholds, nearly all have used fixed, linear-ITD steps (for example, 5.8 μs originally used by Levitt, 1971; more recently, 20 and 5 μs by Trahiotis and Bernstein, 1990). It is recommended here that the stimulus dimension be logarithmically transformed. Such a transformation produces psychometric functions whose slopes are independent of the subject's threshold (i.e., they are parallel). This letter briefly discusses the advantages of log-transformed functions in adaptive psychophysical measurement.[1]

I. PSYCHOMETRIC FUNCTIONS

The following ideas draw from detection theory as well as empirical findings on the shape of psychometric functions (Green and Swets, 1966; Green and Luce, 1975). Figure 1 presents lateralization psychometric functions for one observer (from Saberi and Green, 1994) using a forced-choice constant-stimulus method. The stimulus on each trial was selected from a set of about 20 ITD values. All ITDs had equal *a priori* probabilities of selection on any given trial. Performance for each value was pooled across runs of 100 trials. In the left panel, two functions are depicted. Each function is based on a total of 7000–10 000 trials. The steeper function shows data for the detection of an ITD in a 500-Hz tone and the shallower function, for a sinusoidally amplitude-modulated (SAM) tone with a 50-Hz modulation frequency and a 3.5-kHz carrier. These data may be fitted with the upper half of the normal probability integral with a mean of zero and standard deviation of internal ITD noise equal to σ,

$$\Phi(\mathrm{ITD}) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\mathrm{ITD}} e^{-0.5(y/\sigma)^2}\, dy. \tag{1}$$

The right panel shows the same data and functions as the left panel plotted on log-ITD. On a linear interaural-delay scale, the two fitted functions differ only by a multiple of their standard deviations:

$$\Phi\left(\frac{\mathrm{ITD}}{\sigma_1}\right) = \Phi\left(\frac{\mathrm{ITD}}{c\sigma_2}\right). \tag{2}$$

This difference is equivalent to multiplying the units of ITD for one function by a constant (c^{-1}) in obtaining the other function. The log transform translates ratios into differences; thus multiplying σ by a constant results in a linear shift of Φ_1 along the log-ITD axis in obtaining a parallel function Φ_2 by a magnitude equal to log(c). Since these functions are parallel, they cover the same exact effective range of stimulus values (values which produce probabilities between 0.55 and 0.95). Given a Gaussian fit, this effective range is about one log unit.[2]

The fact that log-transformed psychometric functions are parallel has ramifications for using adaptive methods for threshold estimation. The constancy of effective range suggests that a constant step size in log units (e.g., 0.2) will cover the entire effective range of that function in a fixed number of steps (e.g., 5), independent of σ. On linear coordinates, a fixed step size is problematic because the experimenter has no *a priori* knowledge of the slope of the subject's function. Different stimuli may produce functions with different slopes as in Fig. 1. The choice of a fixed step size in linear coordinates necessarily depends on the steepness of the function which the experimenter assumes for that observer. On a log-stimulus dimension, the functions have identical slopes; thus a fixed logarithmic step size may be chosen for all such functions.

II. MONTE CARLO SIMULATIONS

The detection of interaural delays was simulated for two hypothetical observers using the two-down, one-up (2D1U) and three-down, one-up (3D1U) adaptive methods which track the observer's 70.7% and 79.4% correct response level on their psychometric functions. The simulated observers

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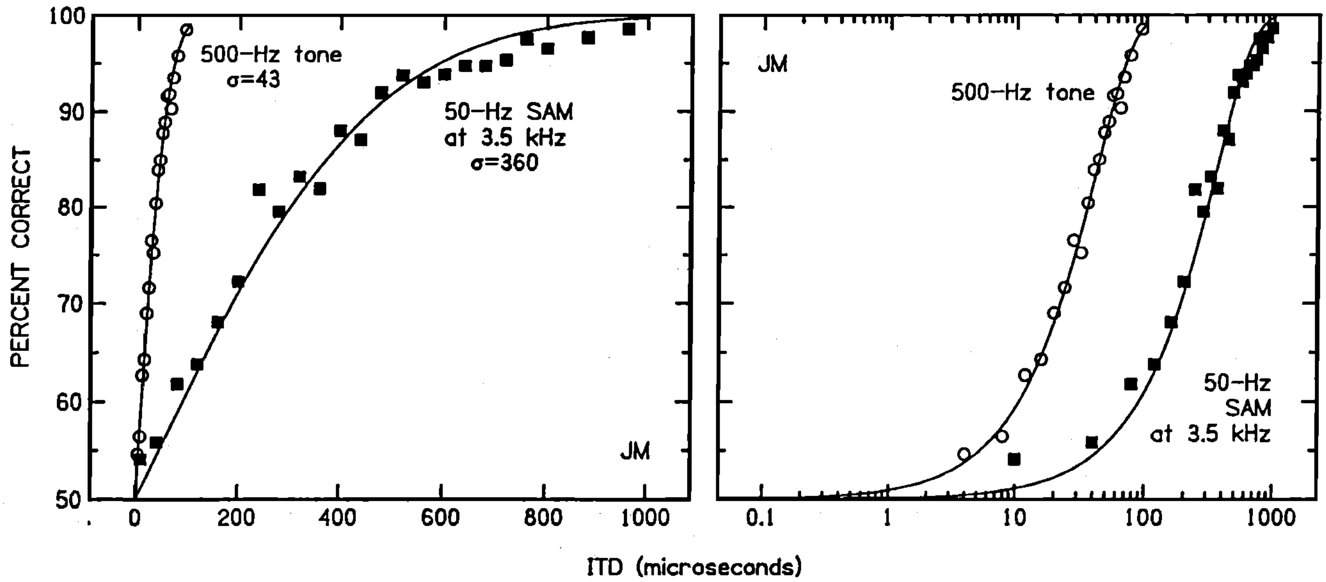

FIG. 1. Lateralization psychometric functions for one subject measured for a 500-Hz tone (steeper function in left panel) and a high-frequency, SAM complex (shallower function in left panel). The task was the detection of an ITD in a forced-choice design. The solid fits are the upper half of the normal probability integral. The right panel plots on a log-ITD axis the same data and functions of the left panel.

had 70.7% thresholds of 25 and 600 μs, and 79.4% thresholds of 36.9 and 902 μs, respectively. Thus observer 1 was substantially better than observer 2 at detecting interaural delays. The assumed form of their psychometric functions was Gaussian with σ's of 45 and 1101 μs, respectively.

The range of naturally occurring ΔITDs is approximately 1300 μs (650 μs leading toward each ear) or about 3.114 $\log_{10}$ units. A step size of 0.2 log-ITD units was used up to the fourth reversal, and 0.05 log-ITD units thereafter (step sizes of 0.2 and 0.05 log units are equivalent to 4- and 1-dB steps for intensive continua). The starting point was 1300 μs. An upper bound of 1300 μs was set for the stimulus range. The first four reversals of each run were eliminated and a threshold estimate for each run was based on the averaged stimulus value on the remaining reversals.

Five thousand, 100-trial runs were simulated for each observer using each up–down rule. The results are displayed in Fig. 2. The top and bottom panels show tracking trajectories for the 2D1U and 3D1U rules, respectively. The ordinate represents the averaged stimulus value on each trial. Results show that with either a 2D1U or 3D1U rule, and a simulated binaural listener with either a low threshold (observer 1) or a high threshold (observer 2), the tracking trajectories reach asymptote at about 20 to 30 trials.

Figure 3 plots histograms of the 5000 simulated threshold estimates for the 2D1U method. The abscissa is linear-ITD units in the top panel, and log-ITD units in the lower panel. These error distributions are nearly equivalent in the bottom panel as expected from the equal slopes of their log psychometric functions.

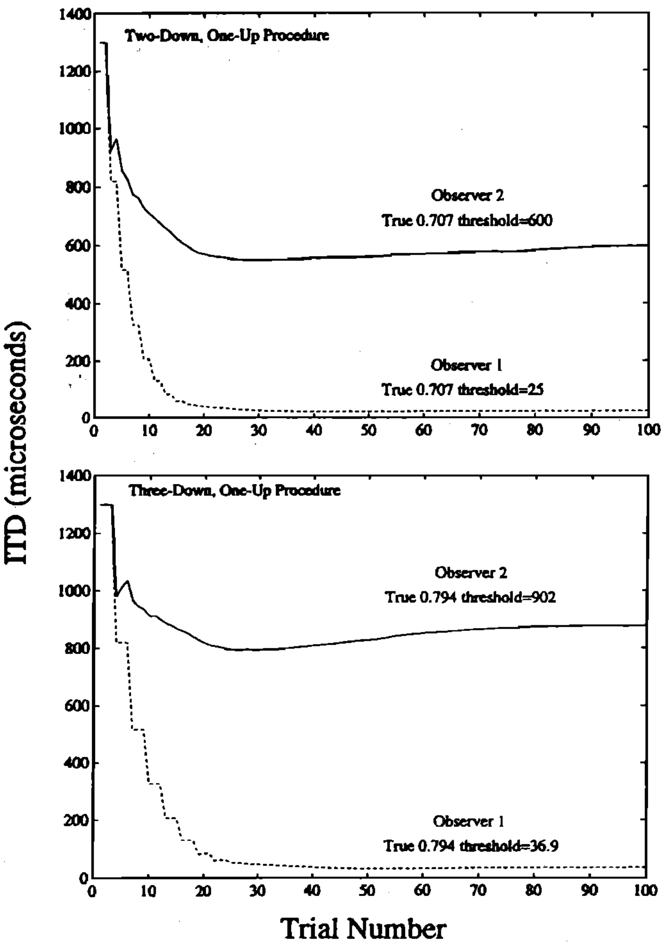

FIG. 2. Tracking trajectories for two simulated observers, using two-down, one-up (upper panel) and three-down, one-up (lower panel) rules. Each track is based on the average of 5000 simulations.

III. HUMAN OBSERVERS

Lateralization thresholds were measured in a two-interval, forced-choice (2IFC) task using the 2D1U rule. The

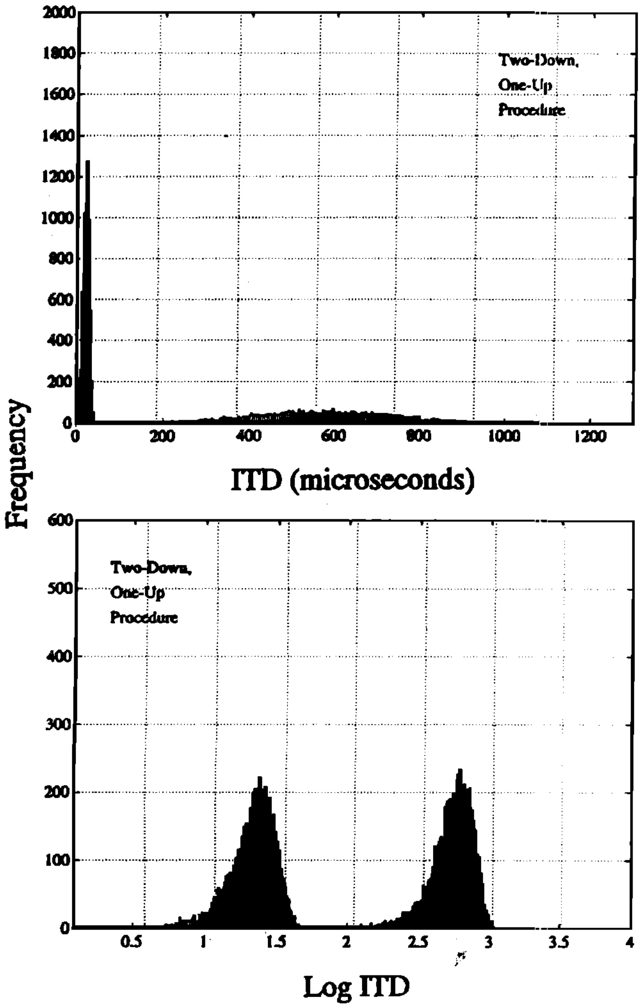

FIG. 3. Distribution of threshold estimates for simulations using the two-down, one-up rule.

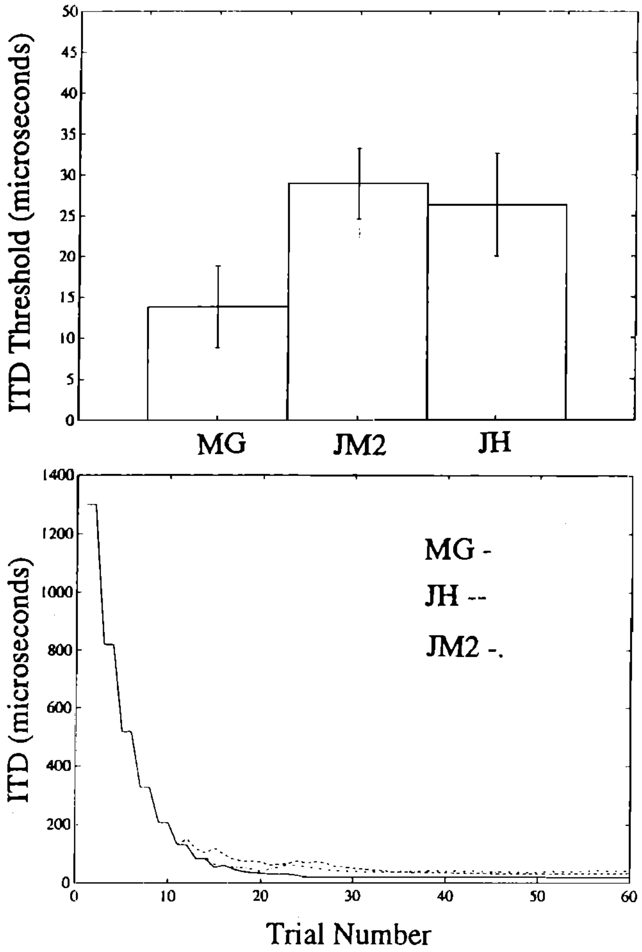

FIG. 4. The upper panel shows lateralization thresholds for a 500-Hz tone for three subjects. Error bars are one standard deviation. The lower panel shows tracking trajectories averaged across seven runs for each subject.

signal was a 400-ms, 500-Hz sinusoid with a 10-ms cosine-squared ramp, and was digitally generated at a sampling rate of 20 kHz (TDT-II), low-pass filtered at 10 kHz (Kemo VBF/24), and presented through Sennheiser HD-450 headphones in a sound-attenuating chamber. When continuously presented, the level of the tone was 60 dB SPL. In one interval of the 2IFC, the ITD of the dichotic tone led to one ear, and in the second interval, the ITD of the same magnitude led to the opposite ear. The subject's task was to determine the order of the perceived laterally displaced images (right–left or left–right). Feedback was provided after each trial. Each of the three normal-hearing subjects (+/− 10 dB of ISO standard between 125 and 8000 Hz) completed seven, 60-trial runs. The parameters of the 2D1U rule were the same as in simulations. The top panel of Fig. 4 shows averaged threshold estimates for each of the three subjects. These values are near the values previously reported for detecting ITDs in a 500-Hz tone (Zwislocki and Feldman, 1956; Klumpp and Eady, 1956; Hershkowitz and Durlach, 1969). The bottom panel shows averaged tracking trajectories for each of the three subjects. The trajectories are asymptotic at about 20 to 30 trials.

IV. SUMMARY

The log transform is principally recommended when psychometric functions on a linear-stimulus dimension are related to one another by a multiplicative factor of the stimulus scale. The log transform will normalize these functions such that they are parallel with a constant effective range. It is this parallel nature of log psychometric functions which motivates the transform. The data of Fig. 1 seem to support such a model for the detection of ITDs. This outcome is also theoretically consistent with the Gaussian assumption of detection theory and seems to be empirically supported by many experimental reports on a variety of other psychophysical tasks (Green, 1960; Weir *et al.*, 1976; Leshowitz *et al.*, 1968; Brown, 1910). Psychometric functions which do not conform to the Gaussian model, of course, do exist. Some are nonmonotonic, to which the up–down adaptive procedures may not be applied. If psychometric functions do not have the properties described above, then the log transform should be considered individually for each case.

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[1]The one exception is Hawley (1994) who also recommends log μs units.

[2]This effective range is 1 log unit when the psychophysical discriminator sees a quantity which is related to the stimulus variable by a *linear* transfer function. Some psychometric functions deviate from this rule and are better fitted with nonlinear power transforms. The log transform will in such cases also produce parallel psychometric functions, but with different effective ranges.

Brown, W. (1910). "The judgment of differences," Univ. Calif. Publ. Psychol. 1, 1–71.

Green, D. M. (1960). "Psychoacoustics and detection theory," J. Acoust. Soc. Am. 32, 1189–1203.

Green, D. M., and Swets, J. A. (1966). *Signal Detection Theory and Psychophysics* (Wiley, New York).

Green, D. M., and Luce, R. D. (1975). "Parallel psychometric functions from a set of independent detectors," Psychol. Rev. 82, 483–486.

Hawley, M. L. (1994). "Comparison of adaptive procedures for obtaining psychophysical thresholds using computer simulations," MS thesis, Department of Biomedical Engineering, Boston University.

Hershkowitz, R. M., and Durlach, N. I. (1969). "Interaural time and amplitude jnds for a 500-Hz tone," J. Acoust. Soc. Am. 46, 1583.

Klumpp, R. G., and Eady, E. R. (1956). "Some measurements of interaural time difference thresholds," J. Acoust. Soc. Am. 28, 859–860.

Leshowitz, B., Taub, H. B., and Raab, D. H. (1968). "Visual detection of signals in the presence of continuous and pulsed backgrounds," Percept. Psychophys. 4, 207–213.

Levitt, H. L. (1971). "Transformed up–down methods in psychophysics," J. Acoust. Soc. Am. 49, 467–477.

Saberi, K., and Green, D. M. (1994). "A maximum-likelihood method for measuring binaural lateralization," J. Acoust. Soc. Am. 95, 2895(A).

Trahiotis, C., and Bernstein, L. R. (1990). "Detectability of interaural delays over select spectral regions: Effects of flanking noise," J. Acoust. Soc. Am. 87, 810–813.

Trahiotis, C., Bernstein, L. R., Buell, T. N., and Spektor, Z. (1990). "On the use of adaptive procedures in binaural experiments." J. Acoust. Soc. Am. 87, 1359–1361.

Wier, C. C., Jesteadt, W., and Green, D. M. (1976). "A comparison of method of adjustment and forced-choice procedures in frequency discrimination," Percept. Psychophys. 19, 75–79.

Zwislocki, J., and Feldman, R. S. (1956). "Just noticeable differences in dichotic phase," J. Acoust. Soc. Am. 28, 860–864.