

Psychometric functions for hybrid difference discrimination/increment detection tasks

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Abstract: Psychometric functions collected from difference discrimination tasks typically have slopes near 1, whereas those from increment detection tasks have slopes near 2. Experiments exploring the effect of stimulus configuration on the psychometric function were undertaken. Some stimuli were configured to conform to difference discrimination and increment detection tasks, while other “hybrid” stimulus configurations had physical properties associated with both tasks. The results suggest that these hybrid configurations may have psychophysical properties that fall in between those found for difference discrimination and increment detection tasks.

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1. Introduction

Researchers have a range of psychophysical procedures and stimulus configurations at their disposal to assist in the estimation of how well an observer can discriminate between a stimulus A (the masker expressed in amplitude units) and that stimulus plus an increment $A + \Delta A$. These procedures are commonly referred to as discrimination tasks. For the two-alternative forced-choice (2-AFC) procedure, a number of different stimulus configurations are possible for discrimination tasks (Laming, 1986). If a sinusoidal masker A is continuous with $A + \Delta A$ in the temporal domain, then the observer is said to be participating in an increment detection task [Fig. 1(a)]. If A and $A + \Delta A$ are separated temporally [Fig. 1(b)], then the task is difference discrimination. Laming (1986) extended the difference discrimination task to include pedestal discriminations, which are difference discriminations with the addition of either a gated or continuous random noise background.

An additional configuration is also possible, constituting a hybrid between increment detection and difference discrimination [Fig. 1(c)]. Such a configuration is not a fanciful notion and has appeared in the literature. Moore *et al.* (1999) used a 3-AFC task in which the masker was a 1000 Hz sinusoid of 70 dB SPL, and duration 300 ms greater than that of the increment. The increments had durations of 5, 10, 20, 50, 100, or 200 ms, and always commenced 200 ms after the onset of the masker, which continued for 100 ms after the offset of the increment. The stimuli presented in each observation interval were of equal duration, and the observer was required to indicate which interval contained the increment. Should this task be considered increment detection or difference discrimination? The observer must choose between three separate stimuli to indicate which contained the increment. This suggests difference discrimination. However, the auditory feature that is to be detected is an increment in a masker of longer duration than the increment: an increment detection. A literature search did little to settle the issue, and a parting comment in a paper by Green *et al.* (1979) on the difference between gated (i.e., difference discrimination) and continuous (i.e., increment detection) pedestal maskers served only to further reinforce our curiosity:

“For how long must a gated masker be left on before it behaves like a continuous masker? We made several attempts to measure this interval with a 100-ms signal by varying masker

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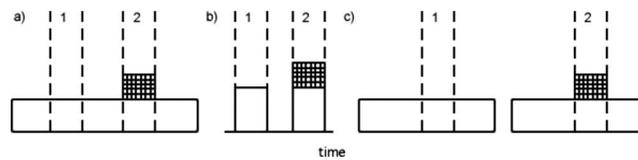


Fig. 1. Three configurations of stimuli amenable to a 2-AFC discrimination task: (a) increment detection, (b) difference discrimination, and (c) a hybrid configuration. Numbers represent observation intervals, the open rectangles the pedestal (i.e., A), and the crosshatched squares an increment (i.e., ΔA).

durations from 100 to 1600 ms. Signals were either centered in the masker, or were presented at a fixed onset asynchrony of 500 ms (McFadden, 1966). Our attempts were not entirely successful. Even at a duration of 1600 ms, the gated masker seemed somewhat more effective than the continuous masker.” (p. 1055).

We conducted a simple experiment to further examine the psychophysical properties of hybrid stimuli similar to that illustrated in Fig. 1(c). Unlike Green *et al.* (1979), who varied masker duration while increment duration remained fixed, we manipulated increment duration and kept masker duration fixed. To provide an empirical test of the effect of our stimulus configurations, we employed Laming’s (1986) sensory analytical model. The sensory analytical model differentiates between two classes of psychophysical tasks that yield different empirical results: the increment detection task [Fig. 1(a)] and the difference discrimination task [Fig. 1(b)]. The model predicts that the increment detection psychometric function is a normal integral with respect to the square of ΔA , while that for difference discrimination will be a normal integral with respect to ΔA .

The psychometric function for discriminating between the two tones, A and $A + \Delta A$, can be explicitly quantified by the equation

$$p(c) = \Phi\left(\left(\frac{x}{\sqrt{2}}\right)^k\right), \quad (1)$$

where $p(c)$ is proportionally correct in a 2-AFC procedure, $\Phi(\cdot)$ is the normal probability integral, x here is $\Delta A/A$,¹ and the slope exponent k is usually estimated from the data [see Laming, 1986, Eq. (4.2)]. Laming’s (1986) model predicts that k will be approximately 1 for difference discriminations and approximately 2 for increment detections. When estimated from empirical data, k is usually a noninteger. The predictions of Laming’s model with respect to k concur with experimental results (e.g., Irwin, 1989).

Our experiment employed trials made up of two observation intervals, one containing a 500 ms tone masker (i.e., A) and the other containing a 500 ms tone masker and an increment (i.e., $A + \Delta A$). The increment was always temporally centered in the masker. The variable manipulated in the study is increment duration, which ranged from 10 to 500 ms. For a 10 ms increment, we would expect, on the tentative assumption that the task is increment detection, the exponent to be approximately 2. For the 500 ms increment (masker and increment duration identical), the task is clearly difference discrimination, and the exponent should be about 1. By varying the increment durations between these two distinct configurations, we obtain a range of hybrid configurations. Thus what is also being tested is where increment detection begins and difference discrimination ends, the very question that interested Green *et al.* (1979).

2. Method

2.1 Observers

Three males, HH (21 years), DS (34 years), and IW (32 years), participated. Each observer underwent an audiometric assessment and none exhibited evidence of clinical hearing loss in the ear to be tested.

2.2 Stimuli and apparatus

Stimuli were 1000 Hz sinusoids generated digitally using LABVIEW 8.5. The masker A was of 500 ms duration with 50 ms ramps (\cos^2). The five increment durations were 10, 50, 100, 200, and 500 ms, each with 5 ms ramps (\cos^2). The increment was always temporally centered in the masker. The masker and increment were rendered on two channels of a 24 bit converter (National Instruments PXI-4461). The masker (Marconi, TF2162) and increment (TDT, PA5) were attenuated before being added in phase (TDT, SM5). For observation intervals containing no increment, the increment attenuator was set to its highest value. The pedestals were presented to the observer at 70 dB SPL via a monaural headset (TDH, 49P) connected to a headphone buffer (TDT, HB5). The observer was seated in a sound-attenuating chamber (Amplaid, Model E).

2.3 Procedure

Observers indicated, on a standard numeric keypad, which observation interval in the 2-AFC task contained the increment. Stimuli in a trial were separated by 200 ms. Warning, observation, and feedback intervals were indicated using light emitting diodes. Observers listened monaurally through the left ear, and the increment was assigned to either of the observation intervals with an *a priori* probability of 0.5. Each session consisted of two blocks of 105 trials each. Each block consisted of a single increment duration, and on any one trial the increment could be one of seven amplitudes (15 trials per increment amplitude), with each increment duration associated with a unique set of amplitudes. Eight blocks of trials were collected for each observer at each increment duration.

2.4 Analysis

For each increment duration, an empirical psychometric function was constructed, with percentage correct plotted against increment-to-masker ratio, $\Delta A/A$. Equation (1), with $x = \Delta A/A$ and a scaling constant a , which effectively positions the psychometric function along the x -axis without changing its shape (Irwin, 1989), was fitted to each empirical function. Both k and a were determined by the method of least squares, with goodness-of-fit indexed by the sum of the squared residuals. The best-fitting values of k and a , along with goodness-of-fit statistics, were obtained using model fitting procedures (specifically the Marquardt–Levenberg algorithm) in-built into SIGMAPLOT 10.

3. Results

Figure 2 illustrates percentage correct as a function of increment-to-masker ratio, $\Delta A/A$, for five increment durations and demonstrates the dependency of percentage correct upon increment size. Each point on the psychometric function is based on 120 trials. The solid curves are the best-fitting psychometric functions, and were determined by taking the average of the best-fitting parameters a and k for the three observers. Table 1 gives values of k for each observer, along with residual sums of squares, which compare favorably with those reported by Irwin (1989). The scalar a accounts for individual differences in acuity and is not so much of interest as is k , the slope exponent. Reference to Table 1, and examination of Fig. 2, indicates an inverse relationship between increment duration and k . That is, as increment duration increases, k decreases. As a consequence of this relationship, the shape of the psychometric functions become shallower as increment duration increases. This relationship is revealed more clearly in Fig. 3, which illustrates individual values of k as a function of increment duration. As a first approximation, a negative-exponential decline in k occurs as increment duration increases, though individual differences are apparent at 50 and 500 ms durations.

4. Discussion

Figure 3 reveals that the results support the hypothesis that a brief (i.e., 10 ms) increment centered on one of two long-duration maskers constitutes an increment detection task, and not a difference discrimination task. For two observers (HH and DS) the exponent k is close to 1.8 for the 10 ms increment duration, though it is closer to 2.2 for IW. For the shortest two increment

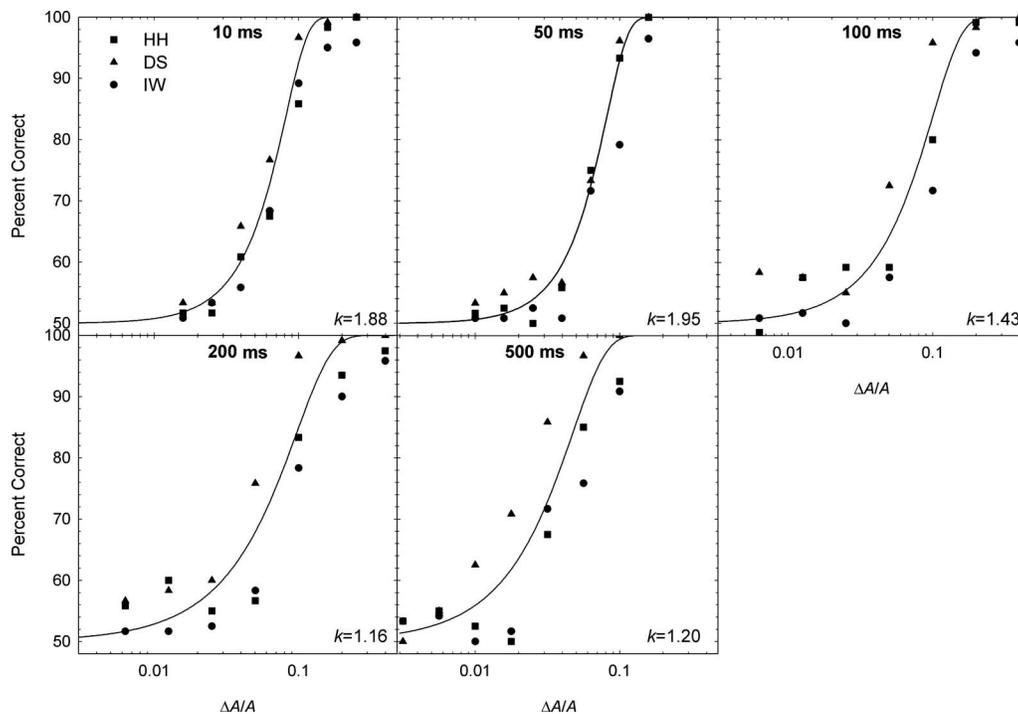


Fig. 2. Data for five increment durations illustrated separately for each observer: HH (■), DS (▲), and IW (●). The solid curves are best-fitting psychometric functions with values of a (not shown) and k (inset) averaged across observers.

durations (10 and 50 ms), a comparison is possible with the data reported by Moore *et al.* (1999), who found a steepening of the psychometric function as increment duration increased from 5 to 50 ms. Figure 3 shows a similar trend for two of the three observers.

At the other end of the increment duration range, 500 ms, support is provided for a difference discrimination task rather than an increment detection task. For two observers (IW and DS), the exponent is close to 1.2, while for HH, the exponent is slightly higher at 1.35. It is worth noting that the latter value results from the worst fit of the predicted psychometric functions to the data (refer Table 1). Notwithstanding this, all three values at the 500 ms increment duration yield 1 when rounded to an integer, and all three values at the 10 ms duration round to 2. This is consistent with the standard predictions made about these two types of task.

Table 1. Best-fitting parameters a and k , and goodness-of-fit indices (SS_{res} and R^2) for three observers and five increment durations.

Increment (ms)	Observer											
	HH				DS				IW			
	a	k	SS_{res}	R^2	a	k	SS_{res}	R^2	a	k	SS_{res}	R^2
10	14.92	1.72	11.51	0.9956	11.16	2.12	43.79	0.9925	9.19	1.79	16.59	0.9786
50	46.53	2.25	29.61	0.9868	28.66	1.55	95.48	0.9779	26.71	2.05	44.71	0.9347
100	20.65	1.31	71.84	0.9110	6.54	1.56	25.65	0.9933	5.52	1.42	86.70	0.9081
200	7.00	1.12	60.94	0.9678	15.81	1.18	58.23	0.9827	5.42	1.18	35.39	0.9687
500	31.01	1.35	114.48	0.9228	55.28	1.12	113.15	0.9595	22.18	1.15	13.38	0.9875

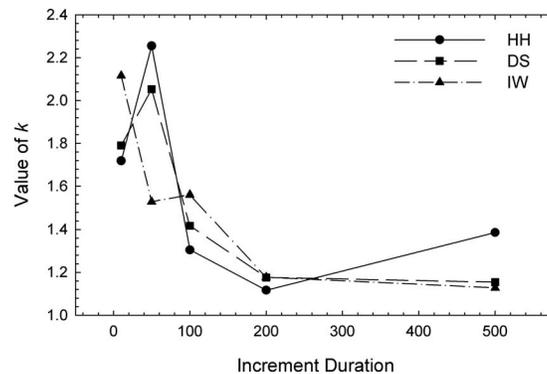


Fig. 3. The slope exponent k as a function of increment duration for three observers.

Of more interest is the relationship between the exponent k and increment duration. With no published data to guide us, we had little basis to predict whether the increment detection task and the difference discrimination task are truly discrete tasks (in which case we might expect a quasi-step function in Fig. 3) or whether the two tasks represent extremes on a continuum with a smooth transition between them for less standard stimulus configurations. Table 1 and Fig. 3 suggest a transition point somewhere between increment durations of 50 and 200 ms. It would be easy to commit the nominal fallacy here. Might the transition between increment detection and difference discrimination be a coalescence: an increment discrimination or difference detection? We are far from convinced that a new category of stimulus configuration with its own unique psychophysical properties would be of much merit, though further investigation is warranted to determine a more exact form of the data presented in Fig. 3. Future studies will need to address the limitations of our study, notably the small number of observers and the small size of the stimulus set.

Results from Moore *et al.* (1999) suggest that increment detection data are more effectively modeled using the Weber fraction expressed in units of intensity (i.e., $\Delta I/I$), while difference discrimination data are better modeled using the level difference, ΔL . Again, with respect to Fig. 3, the question arises as to the nature of the transition between data arising from the difference discrimination task and those arising from the increment detection task. That is, for data of this type, when should $\Delta I/I$ be used as the abscissa and when should this measure be ΔL ? Note, however, that such a consideration is less to do with practicalities and more to do with theory. When the increments are as small as those commonly used in level discrimination procedures, it is possible to choose between $\Delta I/I$, $\Delta A/A$, or ΔL with immunity because of the proportional relationship these measures have to one another. The correct measure cannot be determined from data collected using this typical range of levels (Green, 1993; Moore *et al.*, 1999).

Of additional interest is the transition from increment detection to decrement detection. For increment detection, Moore *et al.* (1999) asserted that the correct measure of the stimulus is $\Delta I/I$, whereas for decrement detection the supported measure is ΔL . Consider a task, with two observation intervals, in which a set of increments or decrements are added or subtracted from a continuous pedestal. If the second interval always contains the increment or decrement, and if the task of the observer is to judge if the second interval was more intense than the first, then the task would be the classical method of constant stimuli. On the basis of the conclusions of Moore *et al.* (1999), the x -axis should be divided into two portions at the point of subjective equality (PSE). Stimulus values below the PSE should be measured in ΔL , and those above the PSE in $\Delta I/I$. Considerations such as these emphasize the importance of resolving the measurement problem in level discrimination (Shepherd and Hautus, 2007).

References and links

¹ $\Delta A/A$ is the measure employed here because Laming's (1986) sensory analytical model, in the course of making quantitative predictions of the slope exponent k assumes $\Delta A/A$.

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