ASSESSING THE SINGLE INTERVAL ADJUSTMENT MATRIX YES-NO TASK

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Abstract

The SIAM Yes-No task is an efficient procedure for estimating absolute thresholds, though arguably requires further assessment prior to its adoption into mainstream psychophysical research. We report two experiments, undertaken on the auditory modality designed to assess the functionality and efficiency of the SIAM procedure. First, an audiometric paradigm was employed in which absolute thresholds were estimated for both left and right ears at seven frequencies. Second, a modified version of the SIAM, the SIAM-Rapid, was compared to the orthodox SIAM procedure using 1000-Hz tones of 100 ms duration. Both experiments demonstrate the efficiency and precision of the SIAM approach.

The bedrock of classical psychophysics is the concept of the sensory threshold. In his seminal work *elements of psychophysics*, Gustav Fechner detailed a number of psychophysical methods affording threshold estimates. However, the advent of modern psychophysics and revised models of sensory processes brought the concept of the threshold into disrepute by demonstrating the influence of nonsensory factors. Despite this, sensory thresholds in psychophysical research and clinical practice remain popular. The resilience of the sensory threshold has encouraged the continuous development of procedures and analyses dedicated to their measurement. This paper assesses a comparatively new method affording the estimation of absolute thresholds, the Single Interval Adjustment Matrix (SIAM) Yes-No procedure, and a modification of the SIAM Yes-No task, the SIAM-Rapid.

Contemporary methods for estimating absolute thresholds centre on adaptive procedures. Prior to the advent of adaptive techniques the method of limits or the *M*-interval forced choice tasks were the mainstay of threshold estimation techniques. The *M*-interval forced choice task is considered the gold standard to which other techniques can be benchmarked, but is itself inefficient due to the weight of the data required to construct the psychometric function from which the absolute threshold is derived. The advent of adaptive techniques, and particularly the transformed up-down methods (e.g., Levitt, 1971), greatly reduced the required labour for both experimenter and participant. Both the Two-Interval Forced-Choice (2-IFC) tasks incorporating either a two-down, one-up or a three-down, one-up adaptive regime are popular methods for estimating absolute threshold. However, a number of drawbacks are associated with these methods, including the possibility of an interval bias contaminating threshold estimates, and the necessity of two observation intervals per experimental trial. For a valid estimate of an absolute threshold at a single acoustic frequency about one hour of testing may be needed using a 2-IFC adaptive procedure. If other frequencies are to be tested then the burden is multiplied. Kaernbach (1990) has developed a single interval technique for deriving valid estimates of absolute threshold that can be considered free of response bias.

The SIAM Yes-No Task

The Single-Interval Adjustment Matrix is an unbiased adaptive version of the Yes-No task. Developed by Kaernbach (1990), it is argued to be as accurate as the 2-IFC two-down, one-up procedure, but uses only half the number of stimulus presentations. As with the standard Yes-No task, a 'yes' or 'no' response is given on each trial. However, with the SIAM procedure, the stimulus intensity is increased or decreased by a predetermined level (step-size), based on the outcome (Hit, Miss, False Alarm, or Correct Rejection) of the judge's response. The threshold can be determined by taking the mean of the stimulus intensity at each turn-around (excluding the first *n* turn-arounds as determined by the experimenter). A typical SIAM trial is displayed in Figure 1A. In this Figure a warning interval (e.g., an LED flash) is followed by a single observation interval that may or may not contain the target stimulus (e.g., a 1000-Hz tone) that the observer is to detect. Feedback is given contingent on response and a new trial presented until some stopping rule is reached.

Kaernbach (1990) devised a 'payoff matrix' which dictates an increase in the stimulus level for a "no" response given to a stimulus trial (Miss), and for "yes" response given to a blank trial (False Alarm). A decrease in stimulus level occurs when a "yes" response is given to a stimulus trial (Hit) and no change on a "no" response given to a blank trial (Correct Rejection). The amount (step-size) of change depends on the target performance (*t*) desired by the experimenter. Table 1 shows the step-size adjustments that can be used for specific target performances. For example, using a target value of 50% "yes" responses require an increase of one step-size when the outcome is a hit.

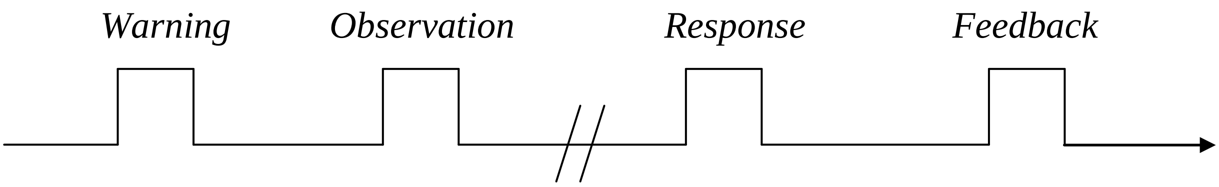
The SIAM-Rapid Task

The SIAM-Rapid (Fig. 1B) is similar to the orthodox SIAM task just described, but with one procedural difference. Whereas the SIAM Yes-No task pauses while waiting for an observer's response (and hence the commencement of the next trial is contingent on response), the SIAM-Rapid does not. Instead, the SIAM-Rapid extracts information from both a response (e.g., a button press) and non-response (i.e., no action) and uses this information to adjust the stimulus magnitude on the next trial. Assuming *t*=0.5 (see Table 1), if a signal is present and the observer indicates as such then the outcome is a Hit (i.e., -1 dB) Table 1), where-as if the observer offers no response then it would be a Miss (i.e., +1 dB). If the signal was not present and the observer guessed it was present then the outcome would be a False Alarm (i.e., +2 dB) or a Correct Rejection if they made no response.

Table 1: Payoff-matrix to determine the step-size adjustments for a SIAM Yes-No task (Kaernbach, 1990).

	t = 0.25		t = 0.33		**t = 0.5**		t = 0.67		t = 0.75	
	yes	no	yes	no	**yes**	**no**	yes	no	yes	no
Signal: 50%	-3	1	-2	1	**-1**	**1**	-1	2	-1	3
Noise: 50%	4	0	3	0	**2**	**0**	3	0	4	0

A) The SIAM Yes-No Task



B) The SIAM-Rapid Yes-No Task

Fig. 1. A schematic representation of trials for the SIAM Yes-No and SIAM-Rapid tasks.

Several researchers have used SIAM and achieved successful results in areas such as visual feature search with hemineglect patients (Brooks, Wong, and Robertson, 2005; and List., et., al., 2008); brightness matching (Brown and Rudd, 1998) and auditory filter measurements (Leeuw and Dreschler, 1998). However, these studies appear to be the only use of the SIAM approach in nearly twenty years of existence. That the use of the SIAM procedure is nearly non-existent in the literature is likely to be due an insufficient degree of assessment that would give researchers the confidence to use the technique. This paper describes two auditory experiments designed to assess the functionality and precision of the SIAM procedure, both for an orthodox version (the SIAM Yes-No) and a modified version (the SIAM-Rapid)

Experiment 1: Auditory SIAM Pilot

Method

Observers

Participants were 6 naïve observers, 2 males (denoted M1, M2) and 4 females (F1 to F4).

Stimuli and Apparatus

Tones, 10 ms in duration, were constructed with 1-ms rise-and-fall times ($\cos^2$). LabVIEW 8.1, 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 and alternatively listened through their left and right ears.

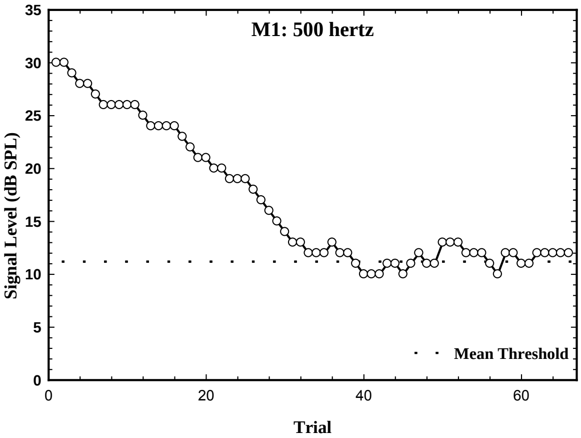


Fig. 2: Plot of signal level as a function of trial number (*n*=70) for an observer (M1) detecting a 500-Hz tone of 10 ms duration. The dashed horizontal line represents the absolute threshold, which was estimated from all but the first two turn-arounds. Four such tracks were obtained in order to derive each threshold estimate displayed in Table 2.

Procedure

An orthodox SIAM Yes-No task (see Figure 1A) was employed to detect absolute thresholds at the following frequencies: 500, 1000, 2000, 3000, 4000, 6000, and 8000-Hz. Each tone was presented at each frequency for 70 trials (490 trials/block). The seven frequencies were presented serially from lower to higher, and only one ear (left or right) was tested on any one block of trials. The task of the observer was to indicate, by a key press, whether they judged the tone to be present or not. Contingent on response the tone either increased, decreased, or remained static, in amplitude according to Table 1 (and *t*=0.5). So, for example, a False Alarm wouldresult in the tone increasing 2 dB.

Results

Figure 2 plots signal pressure (dB SPL) as a function of trial number for Observer M1 listening to a 10-ms 500-Hz tone. Table 2 shows absolutes thresholds for six observers for both left and right ears. Each threshold is the average of four experimental blocks, which themselves terminated after 70 trials, with the first two turn-arounds were discarded from the threshold estimate.

Table 2 : Absolute thresholds (in Db SPL) for six observers (column 1) tested at seven frequencies.

Left	**500**	**1000**	**2000**	**3000**	**4000**	**6000**	**8000**
M1	17.92	10.72	19.65	19.96	17.19	34.74	31.14
M2	25.10	15.56	16.39	16.29	17.11	21.44	25.89
F1	18.88	8.79	9.84	11.38	9.43	19.76	16.40
F2	23.86	9.91	13.87	21.73	16.05	29.48	28.26
F3	29.20	21.02	13.49	24.78	13.75	20.94	28.07
F4	21.20	16.77	14.00	15.63	17.50	22.06	16.64
Right	**500**	**1000**	**2000**	**3000**	**4000**	**6000**	**8000**
M1	23.45	16.03	21.78	17.85	17.22	33.75	15.84
M2	25.40	13.29	14.20	11.10	15.87	15.14	21.43
F1	20.15	11.48	13.59	10.08	9.08	10.66	12.47
F2	23.34	12.12	11.82	11.67	11.91	22.80	24.29
F3	26.14	17.60	8.13	20.19	13.01	13.24	16.99
F4	26.20	22.20	17.84	21.41	17.37	27.30	25.20

Experiment 2: SIAM Yes-No and SIAM-Rapid

Method

Observers

Experiment 2 involved ten participants, five males (M3 to M7) and five females (F5 – F9).

Stimuli and Apparatus

The generation and delievery of stimuli were identical to the SIAM procedure described in Experiment 1. Stimuli were 100 ms duration and 1000-Hz only.

Procedure

In Experiment 2 the observers, when undertaking the SIAM Yes-No task, responded using a box containing a green ("yes") and a red ("no") microswitch. Each trial was as illustrated in Figure 1A, with the next trial contingent on response. For the SIAM-Rapid task observers were asked to press the green switch only if they thought the signal had coincided with the flash of a green LED, and the presentation of the next trial was not controlled by the observer (see Figure 1B) as the response interval was set at a maximum of 100 ms. For both tasks (t=0.5: see Table 1) an experimental block terminated after 15 turn-arounds, with absolute thresholds based on all but the first three turn-arounds.

Results

Figure 3 is a bar graph displaying near threshold estimates for each observer. Visual inspection reveals that thresholds are equivalent regardless of which technique was used, and furthermore, the variability around the estimates appear slightly less for the SIAM-Rapid. Scrutiny of the beginning and end times of the two tasks showed that, across the ten observers, the SIAM Yes-No task took on average 227 seconds, while for the SIAM-Rapid this time was reduced to 155 seconds.

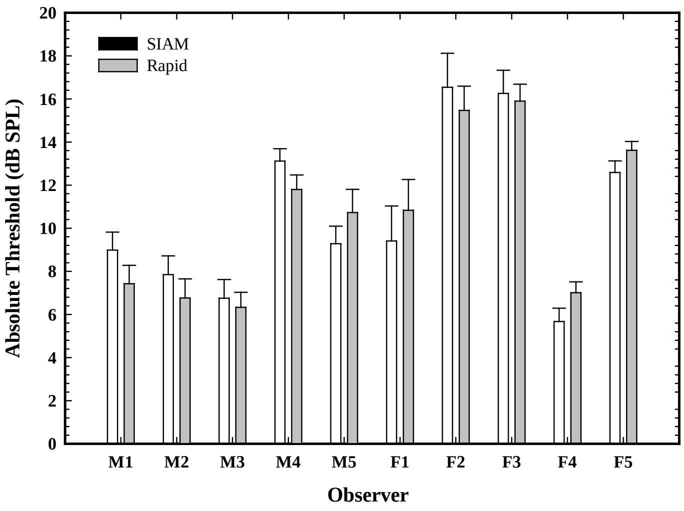


Fig. 3: Bar graph plotting SIAM and SIAM-Rapid absolute thresholds for each observer. Each threshold estimate is the average estimate over ten blocks, and 95% confidence intervals are included.

Discussion

These two experiments establish the viability of the SIAM approach and support the validity of the thresholds estimates it produces. Additionally, Experiment 2 demonstrated that in certain stimulus contexts (here pure tone detection) the SIAM method can be modified to return an even greater efficiency relative to the 2-IFC-based tasks. In Experiment 1 the trends of the data across the seven frequencies are consistent with what would be qualitatively predicted from Equal Loudness Contours. Experiment 2 indicates that the SIAM-Rapid has concurrent validity with the orthodox SIAM Yes-No task, and has the advantage of being quicker. The task could be made quicker still if, like von Bekesey tracking, the feedback interval was removed.

A potential application of the SIAM-Rapid is pure tone audiometry. The pure tone audiogram is a core clinical tool in current audiological practice, and remains the front-line assessment tool in diagnosis and treatment. The diagnostic potency of the audiogram is among the highest in clinical medicine (Margolis, 2005) and since the 1920's the development of electronic audiometry has further advanced this claim. Clinical pure-tone audiometry is, however, extremely time consuming if done properly. The SIAM-Rapid may offer an increase in efficiency that may ultimately allow the return of bias-free threshold estimates to audiology.

Satisfied with the results from these two pilots studies we are currently collecting absolute thresholds for 10-ms 1000-Hz tones using the SIAM Yes-No task, the SIAM-Rapid task, and the 2-IFC two-down, one-up adaptive task. Data collection is sufficiently progressed to enable provisional results to be presented at Galway in 2009. At this point in time the data thus far collected gives us confidence in recommending Kaernbach's (1990) SIAM approach.

Acknowledgments

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