Acknowledgements

This work was supported by a Discovery Grant from the Natural Sciences and Engineering Research Council of Canada (to KHN) and by an Ontario Graduate Scholarship (to LMD).

References

D'Alessandro, L. M. (2008). Quantification of and gender differences in human loudness adaptation: Experiment and theory. *M.Sc. thesis, University of Toronto*.

Hood, J. D (1950). Studies in auditory fatigue and adaptation. *Acta Otolaryngologica*, *92*, 1-57.

Jerger, J. F. (1957). Auditory adaptation. *Journal of the Acoustical Society of America*, *29*, 357-363.

Sagi, E., D'Alessandro, L. M., & Norwich, K. H. (2007). Identification variability as a measure of loudness: An application to gender differences. *Canadian Journal of Experimental Psychology, 61*, 64-70.

Von Békésy, G. (1929). Zur Theorie des Hörens: Über die Bestimmung des einem reinen Tonempfinden entsprechenden Erregungsgebietes der Basilarmembran vermittelst Ermüdungserscheinungen (On the theory of hearing: On the determination of an area of excitation of the basilar membrane, which corresponds to a pure tone, that exhibits fatigue), *Physikalische Zeitschrift, 30,* 115-125.

Von Békésy, G. *Experiments in hearing* (1960). New York, NY: McGraw-Hill, pp. 354-357.

Weiler, E. M., Loeb, M., & Alluisi, E. A. (1972). Auditory adaptation and its relationship to a model for loudness. *Journal of the Acoustical Society of America*, *51*, 638-643.

Weiler, E. M., & Blackmond, H. Jr. (1973). Auditory adaptation: Loudness balancing vs. midplane localization, *Journal of Auditory Research, 13,* 101-104.

AUDITORY FREQUENCY FOCUSING IS EXTREMELY RAPID

Bertram Scharf and Adam Reeves

Northeastern University, Boston, MA (scharf@neu.edu)

Abstract

Auditory threshold is 3 to 5 dB higher when signal frequency changes from trial to trial than when the same on every trial. This threshold increase can be avoided by presenting a weak cue at the same frequency as the signal at the beginning of each trial. To achieve this improvement, Scharf, Reeves, and Suciu (2007) showed that the cue onset must precede the signal onset by at least 200 ms. Threshold increased as signal delay decreased from 352 to 82 ms. It was unclear whether poorer detection at shorter delays was caused by sluggishness in focusing on the correct frequency or by interference from the temporally proximate cue. We now show that the threshold at delays at least as short as 52 ms can be ascribed primarily if not entirely to interference. The implication is that selective frequency focusing is very rapid.

Weak sounds may be detected more easily when preceded by a cue that informs the listener about the frequency content of the following signal (e.g. Green, 1961). Recently, we (Scharf, Reeves, and Suciu, 2007) measured the decrease in threshold as a function of the delay of the onset of a brief signal relative to the onset of a preceding cue. We showed that an ipsilateral cue presented only some 82 ms before a signal of uncertain frequency helped detection but less so than the same cue presented 352 ms before the signal. The improvement in detection decreased monotonically as the signal delay went from 352 to 82 ms. Although we ascribed, tentatively, the decline in detection primarily to the listeners' inability to focus attention rapidly on the target frequency, we indicated the possibility that a cue presented shortly before a signal could interfere with signal processing. To evaluate this possibility, we have now measured detection with *frequency certainty* in the presence of ipsilateral cues. In frequency certainty, i.e. with the signal frequency known before the beginning of a trial, it has been shown that introducing a cue well ahead of signal onset does not improve detection (e.g. Gilliom and Mills, 1976; Scharf, Quigley, Aoki, Peachey, and Reeves, 1987). Accordingly, under the conditions of the present experiment, any increase in threshold with decreasing signal delay would not reflect sluggish frequency focusing; it would reflect some kind of interference by the cue with detection.

Method

All tones, both signals and cues, were 40 ms bursts. The duration of 40 ms does not include the cosine squared rise time of 7 ms and fall time of 5.3 ms; the equivalent rectangular duration equaled 46 ms. Cues and signals were always presented to the left ear. All tones were presented against a continuous background of broadband noise set to a low spectrum level of 12.44 dB. At such a relatively low noise level, Botte (1995) has shown that the attention band is narrower than at higher levels and so would help counter the widening of the attention band with brief signals (Wright and Dai, 1994). The noise was presented binaurally and was in phase at the two earphones.

All the main measurements were made with a single-interval, yes-no procedure so as to have a unique and unequivocal measure of the time between the onset of a cue and the onset of the observation interval. Each trial began always with a visual marker and also with a simultaneously presented auditory cue; an observation interval then followed after a delay that was fixed appropriately for each block of trials. On half the trials a signal was presented during the observation interval, and on the other half no signal was presented. The listener pressed a button to indicate whether or not a signal was heard, upon which the correct answer was indicated. Listeners were encouraged to respond quickly, but no limit was placed on the response interval. Following the response, the next trial began after 850 ms.

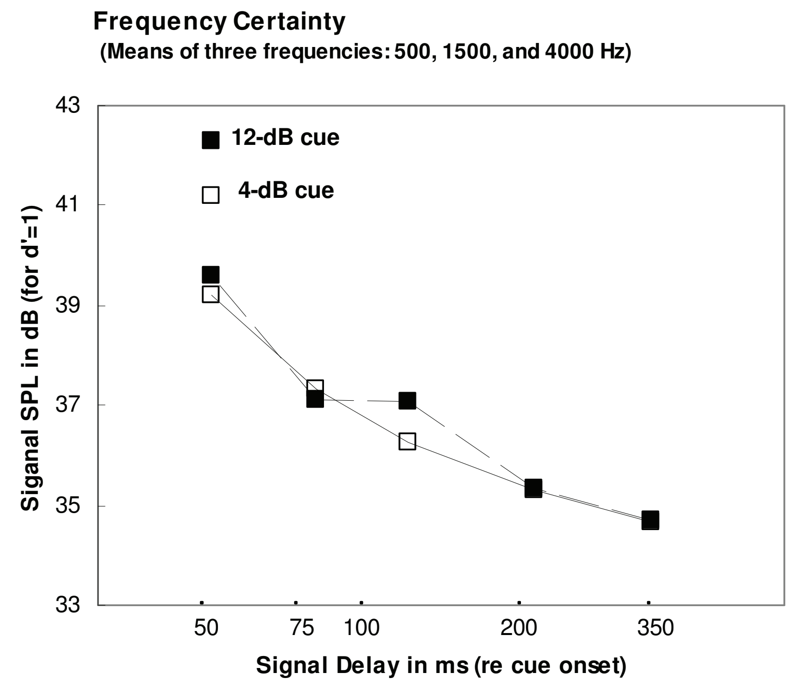
Signal frequencies were 500, 1500, and 4000 Hz. Each frequency was tested on a separate day in a single session lasting about 1 h. At the beginning of a session, masked thresholds at the frequency to be tested that day were measured in the absence of cues by a 2AFC adaptive procedure. Measurements converged on 79% correct. Two or three independent estimates of threshold were thus obtained and used to set the levels of the cues and signals. The rest of the session comprised 11 blocks, including five blocks with an ipsilateral cue and six with a contralateral cue. (Results with a contralateral cue are to be presented elsewhere.) In each block, the signal delay was fixed at 52, 82, 122, 212, or 352 ms. The cue was set to 4 dB above signal threshold or to 12 dB depending on the session. Thus for each listener a total of six sessions (3 frequencies by two cue levels) was run.

Five listeners served in these experiments. All had normal audiometric thresholds as determined at the Northeastern University hearing clinic. All but one laboratory member were paid for their services. Other than the 34-y old laboratory member, all were adults under 25 years. Most had served previously in similar psychoacoustical experiments.

Performance was assessed by calculating d´. We obtained d' = z(H)- z(F), where H is the hit rate and F the false alarm rate, in two ways. In the first way, d's were estimated from the means of hit and false alarm rates over listeners. To facilitate comparisons among conditions, from each d´ and associated signal level (also averaged across listeners) we calculated the signal level required for d´ to equal 1.0. These are the means presented in our figures. In a second way, d' was calculated individually and then converted for each listener to the level for d'=1. These values were used for a repeated-measures ANOVA. (By calculating thresholds on the basis of the means of H and F, we avoid the problem of very high or very low values of H and F common with individual data. The difference between the two sets of thresholds seldom exceeded 0.5 dB.) To calculate the level for d' =1, we assumed that d´ changes with signal level at the rate of 1.0 unit d' per 3 dB. This assumption is based in part on data for short-duration signals in noise, plotted in Green and Swets (1988, p. 193), (See Scharf et al., 2007, for further details.)

Listeners sat in a sound-isolated booth. A Tucker-Davis (TDT) System III signal processor (RP2.1) generated all sounds, sampled at a rate of 48.83 kHz. A microcomputer (Dell Optiplex GX270) controlled the processor and collected data via a response box (TDT BBOX). Sounds were sent through a headphone driver (TDT HB7) to a pair of Sony MDR-V6 headphones. Waveforms, frequency content, and distortion were checked with a wave-analyzer (GRC 1900) and an oscilloscope (Tektronix TAS220). Background noise was generated digitally to resemble an analogue bi-quad band-pass filter with cutoff frequencies at 300 and 6000 Hz.

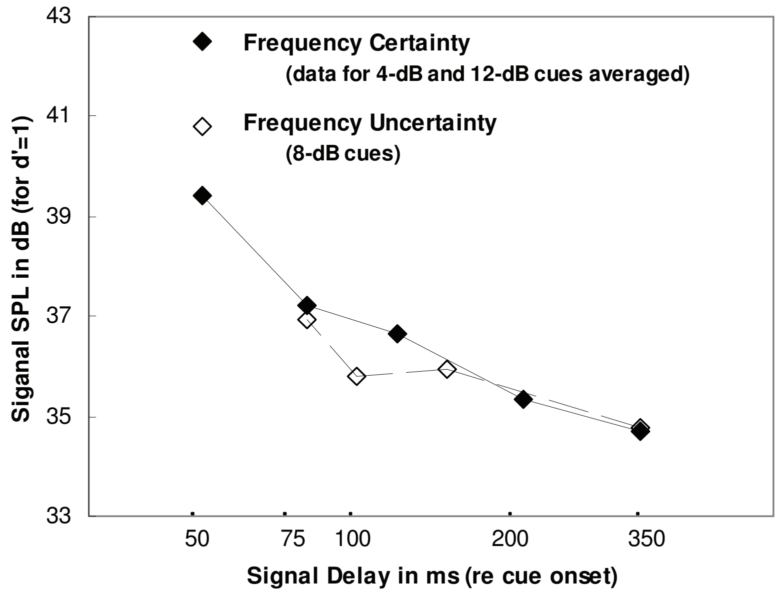
Figure 1. Threshold as a function of signal delay for each of two cue levels.



Results

To facilitate the comparison in Fig. 2 below with data from Scharf et al. (2007), the results for the three signal frequencies have been combined. Moreover, to take into account the release from binaural masking at a low frequency when a monaural signal is presented in binaural noise, as in the present experiment, compared to a monaural signal in monaural noise, as in Scharf et al. (2007), thresholds for the 500-Hz signal were increased 3 dB (cf. Durlach and Colburn, 1978). First, we present the results from the present experiment. The mean signal SPL calculated to yield a d' of 1.0 is plotted in Fig. 1 as a function of signal delay for a 4-dB cue (unfilled symbols) and for a 12-dB cue (filled symbols). (For clarity, no measure of variability is shown; the standard error of the mean hovered around 1 dB under each condition.) An ANOVA shows that the main effect of signal delay is significant ($p < 0.001$); threshold increases as the delay between cue onset and signal onset shortens from 352 to 52 ms for both cue levels. The threshold increase is nearly the same for the two cue levels at all but one signal delay. However, it is to be noted that signal frequency and signal delay interacted significantly ($p < 0.03$); threshold increased more rapidly with decreasing delay as signal frequency decreased. We justify our averaging across frequency because

Figure 2. Threshold as a function of signal delay with frequency certainty (current measurements) and with frequency uncertainty (from Scharf et al., 2007).



Scharf et al. (2007) did not find such an interaction between frequency and delay and because they made too few measurements in the regions of 500, 1500, and 4000 Hz to permit a meaningful frequency-specific comparison with the present data.

Figure 2 presents the mean signal level required to achieve d' = 1 as a function of signal delay. The data labeled frequency certainty (filled symbols) are the averages from the two cue levels shown in Fig. 1. The data labeled frequency uncertainty (unfilled symbols) are results obtained by Scharf et al. (2007). In that experiment, the frequency could come from a logarithmic distribution of frequencies from 570 to 3400 Hz divided into eleven groups of frequencies, each represented an equal number of times. (See Scharf et al., 2007, page 2153 for details). On each trial a cue at the same frequency as the signal preceded the signal. The delay between the onset of the 40-ms cue and 40-ms signal was at a constant value throughout a block of trials and was equal to 82, 102, 152, or 352 ms. The data from Scharf et al. are for signals at all the frequencies tested.

It is to be noted that the cue level in Scharf et al. was 8 dB as compared to 4 and 12 dB in the present experiments. Clearly, the increase in threshold with decreasing signal delay is the same with frequency certainty as with frequency uncertainty. (The close agreement between the means from the two experiments is somewhat surprising since only two of the six listeners served in both experiments.)

Discussion

As the new measurements were made under full frequency certainty, we cannot ascribe the poorer detection at short delays to the listener's need for more time to focus on the signal frequency. Presumably, focusing was maintained throughout a block of trials in the present experiments. It appears that the weak cue, which served no cueing function, interfered with the processing of the signal. Moreover, the interference was the same with frequency uncertainty in Scharf et al. (2007).

Figure 2 shows that threshold increases in similar fashion with decreasing signal delay whether frequency is certain or not. Overall, these results suggest that the threshold increase observed by Scharf et al. (2007) with uncertainty was caused by interference from the cue and did not reflect a sluggish frequency focusing. Indeed, given that the critical band appears to form within at most 5 ms upon auditory stimulation (e.g. Wright & Dai, 1994), it is reasonable that frequency focusing also takes place extremely rapidly. Measurements with frequency uncertain at signal delays briefer than 82 ms are required. In particular, does the accelerated increase in threshold under certainty when the delay was reduced from 82 to 52 ms also occur with uncertainty? Could it be that when focused on a frequency, at very short delays a cue at that frequency is more interfering than cues at other frequencies?

The question arises as to what extent interference from the cue might be a form of forward masking. Our measurements with an ipsilateral cue are superficially like those of forward masking (e.g. Plack, Oxenham, and Drga, 2006) in which threshold is measured as a function of the delay of a signal relative to a preceding masker (our cue). However, none of those measurements of forward masking were made against a background of continuous noise as were ours. More important, no forward masking has been reported at low to moderate masker levels when the masker and signal go to different ears (e.g. Lüscher and Zwislocki, 1949). In stark contrast, our parallel measurements (mentioned above) of the effect of a *contralateral* cue on threshold at short signal delays revealed threshold increases at least as great as with an ipsilateral cue (Fig. 1). Furthermore, essentially no forward masking would be expected from cues as weak as 4 dB above threshold. In fact, Zwislocki, Pirodda, and Rubin (1959), who appear to be the only investigators to have used maskers as weak as our cues, reported the opposite of masking. They measured a 2-dB *decrease* in threshold following a "masker" at 15 dB SL when the masker was a 40-ms, 1000-Hz tone burst and the signal was a 20-ms, 1000-Hz tone burst that came on 80 ms after masker onset. (Other measurements showed that threshold decreased over a range of masker durations from 5 to nearly 100 ms, corresponding to signal delays from 45 to 140 ms.) Zwislocki et al. ascribed the decrease in threshold to "sensitization" as implied by temporal integration. This improvement in detection contrasts strongly with the 4- and 2-dB increases in threshold we measured at 500 and 1500 Hz with a 12-dB cue and a signal delay of 82 ms. Besides the absence of a background noise and the shorter signal duration (20 ms instead of our 40 ms), Zwislocki et al. used a tracking procedure in which the signal level varied up and down. It is not clear why they measured improvement whereas we measured impairment. Clearly, our results cannot in any way be ascribed to forward masking.

Overall, we conclude that most if not all of the increase in threshold with decreasing signal delay reported by Scharf et al. (2007) in frequency uncertainty came about because the cue interfered with signal processing. This interference offset the rapid focusing on the signal frequency afforded by the cue. Parallel measurements with a contralateral cue suggest further that the interference is most likely central in origin.

Acknowledgments

Most of the data were collected by Jennifer Olejarczyk. Zhenlan Jin programmed all the experiments. This research was supported by AFOSR grant FA9550-04-1-0244.

References

Botte, M.-Cl. (1995). Auditory attentional bandwidth: Effect of level and frequency range. *J. Acoust. Soc. Am. 98,* 2475-2485.

Durlach, N. I. and Colburn, H. S. (1978). "Binaural phenomena," In E. C. Carterette and M. P. Friedman (Ed.), *Handbook of Perception Vol. IV*, New York: Academic Press, pp. 365-466,

Gilliom, J. D., and Mills, W. M. (1976). Information extraction from contralateral cues in the detection of signals of uncertain frequency. *J. Acoust. Soc. Am. 59,* 1428-1433.

Green, D. M. (1961). Detection of auditory sinusoids of uncertain frequency. *J. Acoust. Soc. Am. 33,* 897-903.

Green, D. M., and Swets, J. A. (1988). *Signal Detection Theory and Psychophysics* . Los Altos, CA.: Peninsulat Publishing Inc. (revised edition).

Liischer, E. and Zwislocki, J. (1949). Adaptation of the ear to sound stimuli. *J. Acoust. Soc. Am. 21,* 135-139.

Plack, C. J., Oxenham, A. J., and Drga, V. (2006). Masking by inaudible sounds and the linearity of temporal summation. *J. Neurosci. 26,* 8767–8773.

Scharf, B., Quigley, S., Aoki, C., Peachey, N., & Reeves, A. (1987) Focused auditory attention and frequency selectivity. *Percpt. and Psychophys, 42,* 215-223.

Scharf, B., Reeves, A., and Suciu, J. (2007), The time required to focus on a cued signal frequency. *J. Acoust. Soc. Am. 121,* 2149–2157.

Wright, B. A. and Dai, H. (1994). Detection of unexpected tones with short and long durations. *J. Acoust. Soc. Am.* 95, 931-938.

Zwislocki, J., Pirodda, E., and Rubin, H. (1959). On some poststimulatory effects at the threshold of audibility. *J. Acoust. Soc. Am. 31*, 9-14.

MORE ON THE PSYCHOPHYSICS OF CONTINGENCY ASSESSMENT

Lorraine G. Allan[1], Samuel D. Hannah[1], Matthew J. C. Crump[2], & Shepard Siegel[1]

[1]Department of Psychology, Neuroscience and Behaviour, McMaster University, Hamilton ON, L8S4K1, Canada

[2] Department of Psychology, Vanderbilt University, Nashville TN, 37203, USA

allan@mcmaster, hannahsd@mcmaster.ca, matthew.j.crump@vanderbilt.edu, siegel@mcmaster

Abstract

The study of contingency assessment involves examination of the relationship between physical events (the statistical contingency between cue and outcome) and the observer's internal experience of these events. Psychophysics is the discipline relating physical events and internal experiences, so it is surprising that few psychophysicists have been concerned with contingency assessment. At ISP 2006, I described a new methodology – the streamed-trials procedure – to study contingency assessment within a psychophysical framework. More recently we have modified the procedure so that (1) we can use cues and outcomes traditionally used by contingency researchers (e.g., ingestion of certain foods and the occurrence of an allergic reaction), (2) we can assess the observer's assessment of control over the outcome (as well as the observer's assessment of the cue-outcome contingency), and (3) we can study cue interaction effects (e.g., blocking). In addition to describing these modifications, we discuss the value of a psychophysical approach in evaluating theoretical accounts of contingency assessment.

The tasks that have been used to study how an observer assesses the relationship between two binary events can be categorized as passive and active. On each trial of the passive task, a cue may, or may not, be presented, following which an outcome may, or may not, be presented. After a series of trials, the observer is asked about the strength of the relationship between the cue and the outcome. On each trial of the active task, the observer has the option of responding or not responding, following which an outcome may, or may not, be presented. After a series of trials, the observer is asked about how much control they had over the outcome. The relationship between the cue/response and the outcome can be summarized as a 2 x 2 matrix (see Table 1), where the cue or response is represented as the input variable. On each trial the input either occurs (I) or does not occur (~I), and then the outcome either occurs (O) or does not occur (~O). The letters in the cells (a, b, c, d) represent the joint frequency of occurrence of the four input-outcome combinations in a block of trials. One commonly used measure of the contingency between the input and the outcome is ΔP (Allan 1980):

Table 1: The 2 x 2 matrix for the input-outcome pairings in a contingency assessment task.

Input	Outcome	
	O	~O
I	a	b
~I	c	d

$$\Delta P = P(O \mid I) - P(O \mid \sim I) = \frac{a}{a+b} - \frac{c}{c+d}.$$