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Study on detectability of signals by utilizing differences in their amplitude modulation

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Abstract

Auditory search experiments were conducted to investigate the detectability of targets with regard to movements in temporal envelopes. The movements in the temporal envelopes of signals were defined as the mean value of slopes, i.e., the first-order approximation of the temporal envelopes. The movements were systematically controlled by band-pass filtering on the modulation spectrum of the signals. The movements that we used in the experiments were 44, 154, 264, 374, 484, 594, and 704 mV/s. The movements of target signals were set at 264, 374, 484 mV/s. The movements of background signals in each target were set to be different from the movements between target and background signals. Stimuli were composed of different temporal envelopes with a noise carrier. $1/2$-octave band-noise as a carrier was used in which the center frequency of the carrier was 1380 Hz. The results obtained from auditory search experiments demonstrated that the detectability of each target signal could be improved when the movements of the target and background signals differed. The results revealed that the difference in the movements of the temporal envelopes of signals affected the detectability of the signals.

1. Introduction

Audible alarm signals are used to attract the attention of people in many everyday activities, e.g., the beeps and melodic sounds of electronic products that alert us of providing start and end times and the sounds of fire alarms in emergencies [1]. Therefore, these signals must be perceived accurately and efficiently by everyone. Alarm signals with many different stimulus signatures have been studied for this purpose to check if they can be adequately perceived, e.g., by Mizunami *et al.* [2]. There are, however, cases where alarm signals cannot be correctly perceived in real environments because they are masked or partially masked by background noise, and only the person they are intended for knows when and what events have occurred. Therefore, it is important to present alarm signals in such a way that they can be correctly detected in any environment. Here, we can replace the detectability of target signals with auditory search tasks.

Asemi *et al.* [3], in a study that had a close relationship to ours, carried out research on auditory search tasks. Narrow-band noise and pure tones were used and temporal fluctuations in the target were controlled in their experiments as cues to investigating improvements in the detectability of target signals. Their results indicated that temporal fluctuations in the target against background signals played a role in improving detectability.

Based on their results, Kusaba *et al.* investigated how much temporal fluctuations between the target and background signals could improve detectability of the target signal in auditory search experiments [4]. Their results suggested that less similarity in temporal fluctuations between the target and background signals could improve the detectability of the target in noisy environments. However, as they used directed narrow-band noise as stimuli in their experiments, the temporal fluctuations were not controlled.

We defined movements in our previous study and carried out auditory search experiments by using controlled movements. The results suggested that the detectability of target signals was improved as the difference in the movements increased. This tendency constantly appeared when the movement of the target signal was greater than that of the background signal [5]. However, this experiment had two factors for movement and the carrier frequency, so that we could not investigate the factor for movement only.

We investigated the relationship between movements and the parameters of the BP filter in this study. Based on this investigation, we generated stimuli where the values for the difference in the target for the movements and background signals were evenly distributed, and we carried out an auditory search experiment. We considered that the detectability of a signal was affected in this way by utilizing movements in temporal envelopes and determined whether or not we would be able to control the detectability of signals through movements.

2. Movements in temporal envelopes of signals

2.1. Definition of movements

We defined movements in the temporal envelope of a signal

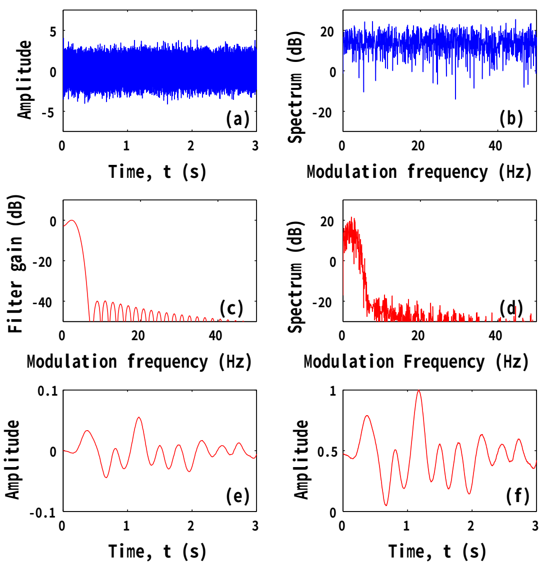

Figure 1: Examples of generation of stimuli: (a) white noise, (b) modulation spectrum of white noise, (c) bandpass (BP) filter on modulation spectrum, (d) modulation spectrum of BP-filtered noise, (e) amplitude envelope, and (f) normalized amplitude envelope.

as the mean value of slopes as a first-order approximation of temporal envelopes [5].

$$v = \frac{A_0}{N-1} \sum_{n=2}^{N} \frac{|P_n - P_{n-1}|}{T_n - T_{n-1}}, \tag{1}$$

where P_n represents the values of peaks/dips in temporal envelopes, T_n is the time, and N is the number of peaks/dips. Here, A_0 is a normalized factor and this is set to be the output reference voltage (using the TDT SystemIII and SANSUI AU-α 907MR Integrated Amplifier). The A_0 in this experiment was 88 mV. Therefore, v was in millivolts per second.

2.2. Control of movements

We systematically controlled the movements defined above with by bandpass (BP) filtering on the modulation spectrum as follows. We assumed that signals could be expressed by multiplying the temporal envelope with the carrier. Here, band-noise was used as the carrier.

Figure 1 shows an example of the generation of stimuli that we used in the auditory search experiment. White noise was used to generate the stimuli, as shown in Fig. 1(a). Figure 1(b) shows the modulation spectrum of (a). Figure 1(c) shows the characteristics of the BP filter at the modulation frequency. This filter has a bandwidth of 2.5 Hz at the CF of 2 Hz. The processed modulation spectrum was obtained by BP filtering on the modulation spectrum shown in Fig. 1(d). The processed amplitude envelope was then obtained from the inverse Fourier transform shown in Fig. 1(e). This was normalized by the averaged value for amplitude to be ± 0.5. Stimuli were generated by multiplying the temporal envelopes with the carriers. The rising and falling edges of the stimuli were created as a 30-ms raised-cosine.

We systematically controlled the envelopes shown in Fig. 1(f) by using Eq. (1) to control movements in the temporal envelopes. As in the above, various movements were generated by systematically controlling their modulation spectrum using the BP filter.

Table 1: Relationship between movements and parameters of BP filter

CF (Hz)	bandwidth (Hz)	movements (mV/s)
2.00	1.0	88
4.75	1.5	308
9.25	1.5	528
11.50	1.0	748
14.25	1.5	968
16.25	1.5	1188
20.00	1.0	1408

2.3. Relationship between movements and parameters of BP filter

We investigated the detectability of signals based on differences in the movements of target and background signals in this study. To do this, we needed to generate stimuli where the differences in movements became equal. We calculated the values for the movements of temporal envelopes by BP filtering, which used various CFs and bandwidths for the BP filter, to investigate the relationship between the movements and parameters of the filter. Table 1 summarizes the relationship between the movements and parameters of the BP filter.

Furthermore, Figure 2 plots the distribution in the values of movements obtained from each BP filtering on the modulation spectrum. We pegged the mean of values for movements at a movement obtained from BP filtering on the modulation spectrum. The CF and bandwidth of the BP filter were set in such a way that each value for different movements was 220 mV/s.

We found from this figure that the movements tended to increase commensurately as the CF of the filter increased. Therefore, we could systematically control the movements by varying the parameters of the filter.

3. Auditory search experiment

3.1. Aim

We carried out an auditory search experiment for the target and background signals with different movements added to

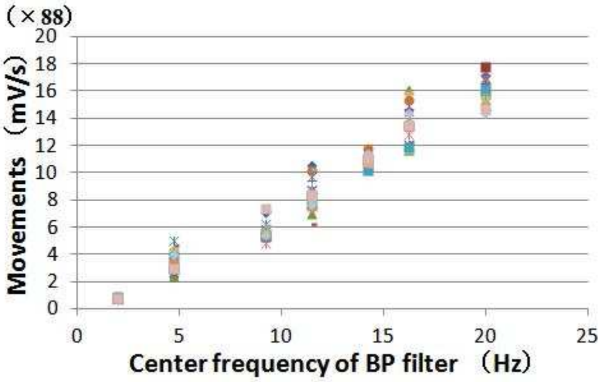

Figure 2: Distribution in movements obtained from modulation spectrum controlled by BP filtering.

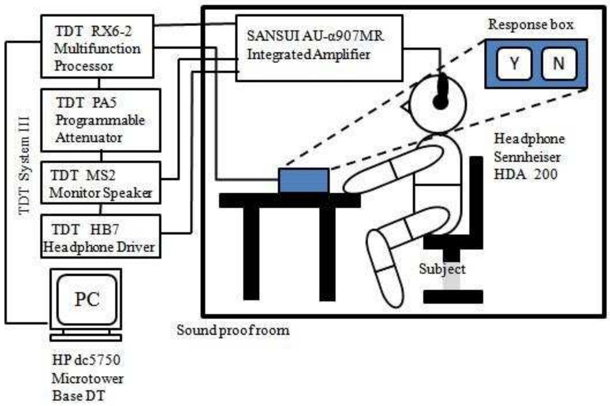

Figure 3: Experimental apparatus.

investigate the detectability of the target with regard to movements in temporal envelopes.

3.2. Stimuli

The movements in temporal envelopes that we used in the experiment were 44, 154, 264, 374, 484, 594, and 704 mV/s. Three of them–264, 374, and 484 mV/s–were used as target signals. The movements of background signals in each target were set to be different from the movements between target and background signals. When the movement of the target was 264 mV/s, the movements of the background were 44, 154, 374, and 484 mV/s. When the movement of the target was 374 mV/s, the movements of the background were 154, 264, 484, and 594 mV/s. When the movement of the target was 484 mV/s, the movements of the background were 264, 374, 594, and 704 mV/s. Stimuli were composed of different temporal envelopes with a noise carrier. $1/2$-octave band-noise as a carrier was used in which the center frequency of the carrier was 1380 Hz.

3.3. Procedure

There were two kinds of assessments in the auditory search experiment, i.e., positive and negative. Stimuli as the target and background signals were simultaneously presented to the participants via headphones in the positive assessments. Stimuli as background signals and band-noise in which movement was not controlled were simultaneously presented to the participants in the negative assessments. The participants were required to determine whether they heard the target signal with the background signal and to press a “Y (yes)” or “N (no)” button on the response box. Before the participants started the sessions in this experiment, a target signal was repetitively presented to them so that they could learn the target signal that would be presented in the session. There were a total of 240 trials in the session (three target signals $\times$ four background signals $\times$ two assessments (positive and negative) $\times$ ten repetitions). These trials were randomly presented.

3.4. Apparatus

Figure 3 has a diagram of the apparatus we used in the experiment, which was carried out in a sound-proof room. Stimuli were generated by Tucker-Davis Technologies (TDT) System III and presented to each subject through an amplifier (SANSUI, AU-α) and headphones (Sennheiser HDA200). Subjects’ responses were recorded through the response box.

4. Results

We obtained the detectability of the target signal, i.e., d', from the results of the assessments done by the participants. There were four classifications of the results for the assessments: Hit (they pressed “Y” when there was a target), Miss (they pressed “N” even though there was a target), False Alarm (they pressed “Y” even though there was no target), Correct Rejection (they pressed “N” when there was no target). Greater values for d' indicated that the target signal was easily detected.

Figure 4 plots the detectability of the target signal obtained by using the difference between movements in the temporal envelopes of the target and background signals. The movement in target signals was 264 mV/s. Figure 5 plots the detectability of target signals when the movement of the target was 374 mV/s. Figure 6 plots the detectability of target signals when the movement of the target was 484 mV/s.

The results demonstrated that the detectability of target signals was improved when the movements of the target and background signals differed. They also suggested that the target signals were easily detected by applying different movements to the target and background signals.

We used band-noise that had the same CF and bandwidth as the carrier of the target and background signals in this experiment. The target and background signals passed through the same auditory filter under these conditions. This indicated that these two signals were decomposed into one component as one sound. Thus, it was extremely difficult to separate the two signals. However, under such difficult conditions, these results suggest that we could perceptually separate two sig-

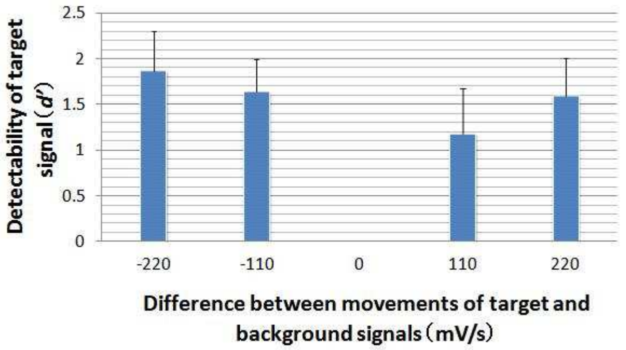

Figure 4: Detectability of target signals obtained by using the differences in movements (movement of target was 264 mV/s).

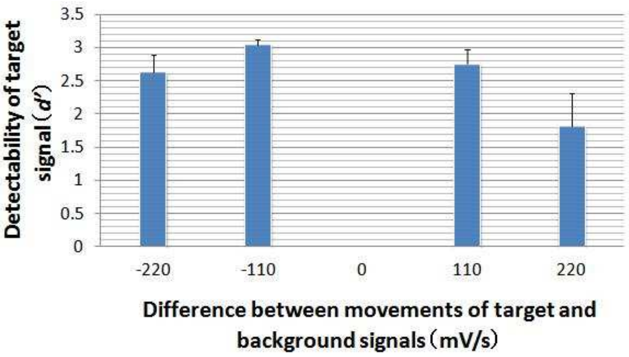

Figure 5: Detectability of target signals obtained by using the differences in movements (movement of target was 374 mV/s).

nals and detect a target signal by perceiving the amplitude modulation of the signals.

We obtained results in our previous study where the detectability of target signals was improved as the difference in movements increased. However, there was little to distinguish the detectability of signals in these results, in comparison with cases where the difference in movements was 110 mV/s and cases where the difference in movements was 220 mV/s. This was attributed to the fact that we could completely separate the two signals when the difference in movements between the target and background signals was only 110 mV/s, so that detectability remained constant even if we used further differences. We did not examine perceptual differences in movement in this experiment. Therefore, we need to set experimental conditions in investigations that are not based on physical but perceptual differences in movements to find how differences in movements affect the detectability of target signals.

5. Conclusion

We defined movements in the temporal envelopes of signals and proposed a method of controlling these movements.

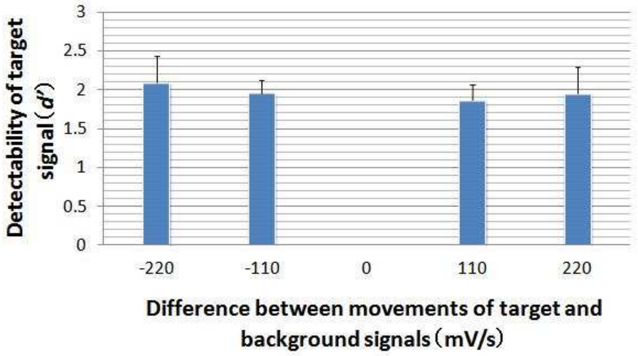

Figure 6: Detectability of target signals obtained by using the differences in movements (movement of target was 484 mV/s).

The auditory search experiments were carried out by using target and background signals with different movements. The results demonstrated that the detectability of target signals could be improved when the movements of the target and background signals differed. This indicated that the amplitude modulation of signals was closely related to the detectability of target signals. We discovered that the detectability of signals could be controlled by utilizing differences in movements.

Acknowledgments

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