1pPPb18. The influence of feature detection on working memory in complex auditory fields

AnneMarie Chiodi*, Aurora J. Weaver and Dennis T. Ries

*Corresponding author's address: Ohio University, Athens, Ohio 45701, ac175509@ohio.edu

Research reveals that feature detectors may enhance listener performance in auditory detection tasks involving frequency modulation (FM) [Cusack and Carlyon, J. Exp. Psychol. 29, 713-725 (2003)]. The influence of these detectors on discrimination of auditory information is mostly unknown. This study investigated the impact of FM on listener performance in auditory, delayed-comparison tasks for conditions that differed in the number of background stimuli within two perceptual windows separated by various retention intervals. The background stimuli within both windows were either all modulated sinusoids or pure-tones for a given trial. An additional stimulus was presented in each window that could differ in its modulation state (FM or unmodulated sinusoid) across the two windows. The temporal placement and frequencies of all stimuli within the first window were assigned randomly for a given trial and the second window followed these parameters. Listeners were to determine whether the two windows were the same or different. Preliminary results show that same-different judgments of target modulation state was easier in a field of unmodulated sinusoids than vice versa. This result occurred regardless of retention interval length, but was influenced by the number of stimuli present. The further influence, if any, of memory span will be discussed.

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INTRODUCTION

The auditory system has been shown to be sensitive to some acoustic features of sound, a process termed feature detection. This automatic process responds selectively to salient qualities of auditory stimuli. Feature-selective neuronal activity has been demonstrated in animal studies for acoustic traits such as frequency modulation (e.g., Rees and Møller, 1983; Bieser, 1998), amplitude modulation (e.g., Rees and Møller, 1983), and duration (Chen, 1998). Cusack and Carlyon’s (2003) behavioral study on perceptual asymmetries in human audition found that frequency-modulated targets are easier to detect in a field of pure-tone distracters than vice versa. The result of such feature detection is improved performance on some sensory tasks, presumably through activation of specialized neural structures. The present study investigates whether feature detection influences discrimination of auditory information as a function of listening field complexity, retention interval duration, and working memory span.

METHODS

Participants

Three adult participants (aged ≥ 18 years) in good health were recruited for this study from the Ohio University population. They received no compensation for their participation. All participants had pure tone, air-conducted thresholds within normal limits (≤ 15 dB HL) for octave frequencies from 250 through 8000 Hz. Each completed (1) a basic background information form to rule out any abnormal auditory processes and attention functions and (2) an informed consent form in accordance with the approval of the study by the Institutional Review Board at Ohio University.

Stimulus characteristics and presentation

All stimuli were created and stored as wav files prior to presentation using Matlab software (The Mathworks, Natick, MA). Output was generated by System 3 hardware (Tucker Davis Technologies, Alachua, FL) controlled by a Pentium 4 computer (Dell, Round Rock, TX) running Matlab and RPVD (Tucker Davis Technologies) software. The signals were verified electrically using a dynamic signal analyzer (Stanford Research Systems, Sunnyvale, CA) and a digital storage oscilloscope (Tektronix, Richardson, TX). Acoustic verification was measured using a sound level meter and 2cc acoustic coupler (Brüel and Kjær, Naerum, Denmark). The stimuli were presented diotically through ER-2 insert earphones (Etymotic Research, Elk Grove Village, IL) to participants seated in a double walled, sound attenuating booth (Industrial Acoustics Corporation, Bronx, NY).

Stimuli were frequency-modulated (FM) and steady-state pure tones with durations of 250 ms, including 10 ms Blackman-Harris onset and offset ramps. These stimuli were generated at an approximate sampling rate of 48,828 Hz and low pass filtered at roughly 24,000 Hz. The frequency of each tone on a given trial was selected randomly from a range extending from 262 Hz to 4192 Hz. All stimuli were presented at a level of 72 dB SPL. As per Cusack and Carlyon (2003), the FM stimuli were modulated at a rate of 8 Hz with a depth of 5% of the center frequency.

Procedure

Screening Test – ACPT

The ACPT is an assessment tool used to determine if an individual has attention difficulties. A score of 86% correct or better indicates whether that individual has attention skills within the normal range. The participant listens to single words presented diotically, and is instructed to indicate when the target word, “dog” is heard. This test was administered to determine whether any participants had inadequate attention skills and should be eliminated from participating in the study. No participants were excluded based on this criterion.
**Discrimination Task**

A discrimination task employing the inter-window intervals in the retention task (see below) was used to determine whether participants were able to hear the difference between FM and pure-tone stimuli. The participants compared two stimuli separated by a 500, 2000, or 4000 ms inter-stimulus interval, each stimulus being either a FM or pure tone, and indicated whether the sounds were the same or different. The participant needed to obtain a minimum score of 90% in order to move on to the span and retention tasks. No participants were excluded based on this criterion.

**Memory Span Task**

The span task employed quantified the number of modulated and steady stimuli a listener could retain in sequence reliably. The task is similar in concept to pitch pattern tests commonly used in clinical APD evaluations except that the length of the pattern to be recalled was adjusted adaptively based upon the participant’s performance. The procedure begins with an experimental trial comprised of a sequence of three tokens, each 250 ms in duration including 10 ms Blackman-Harris, onset/offset ramps. Tokens were separated by a 200 ms inter-stimulus interval. Each token was either a FM or pure tone at 441 Hz. A touch screen display appeared following the presentation of the sequence for a given trial. The participant identified the order in which the tokens were heard by pressing the appropriate button within each vertically oriented column. Incorrect identification of any of the tokens presented on a given trial resulted in a reduction of the token-sequence length by one; correct responses on three consecutive trials for a given sequence length resulted in the addition of another token. In this manner the procedure provides indirect participant feedback following each correct or incorrect response; no explicit feedback was provided. A run terminated once 4 reversals were obtained, and the mean of the sequence length across all reversals was used to determine the span for each run. Three practice runs were completed prior to formal data collection. The mean across 3 additional runs provided an estimate of a participant’s overall memory span for modulated and unmodulated stimuli. Stimuli in this experiment were presented at a level of 72 dB SPL.

**Retention Task**

On each trial, two fields (windows) of stimuli, a standard and a comparison, were presented. Each field contained 1 target and up to 4 distracter tones. In the standard window, the tones were randomly distributed in frequency (262 Hz to 4192 Hz) and temporal location within a 2 s window. One of the tones served as the target and the remainder, if present, as background distracters. The end of the standard and the beginning of the comparison windows were separated by a retention interval of 0.5, 2.0, or 4.0 s. The potential difference between the windows was based on the FM or pure-tone state of the target in both fields as per the specific condition; all other aspects within both windows were identical. Participants judged whether the comparison field was the Same or Different than the standard field by pressing a box labeled “S” for same or “D” for different on a touch-screen monitor. No feedback was given.

Eight target/distractor conditions were used (see Table1). In four of the conditions, the background tones were modulated, and in the other four the background tones were unmodulated. The target tones were either modulated or unmodulated in one or both windows, depending on whether the trial presented was Same or Different. A block for each retention interval consisted of two runs. Each run was comprised of 96 trials with 12 trials presented per condition. Conditions were presented in a random order across each run. Listener performance for standard and comparison fields containing 0, 1, 2, and 4 distracter stimuli were obtained.

**TABLE 1.** Background and target states in the standard and comparison stimulus windows per condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Background Stimuli</th>
<th>Field 1 Target</th>
<th>Field 2 Target</th>
<th>Correct Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unmodulated</td>
<td>Unmodulated</td>
<td>Unmodulated</td>
<td>Same</td>
</tr>
<tr>
<td>2</td>
<td>Unmodulated</td>
<td>Unmodulated</td>
<td>Modulated</td>
<td>Different</td>
</tr>
<tr>
<td>3</td>
<td>Modulated</td>
<td>Modulated</td>
<td>Modulated</td>
<td>Same</td>
</tr>
<tr>
<td>4</td>
<td>Modulated</td>
<td>Modulated</td>
<td>Unmodulated</td>
<td>Different</td>
</tr>
<tr>
<td>5</td>
<td>Unmodulated</td>
<td>Modulated</td>
<td>Modulated</td>
<td>Same</td>
</tr>
<tr>
<td>6</td>
<td>Unmodulated</td>
<td>Modulated</td>
<td>Unmodulated</td>
<td>Different</td>
</tr>
<tr>
<td>7</td>
<td>Modulated</td>
<td>Unmodulated</td>
<td>Unmodulated</td>
<td>Same</td>
</tr>
<tr>
<td>8</td>
<td>Modulated</td>
<td>Unmodulated</td>
<td>Modulated</td>
<td>Different</td>
</tr>
</tbody>
</table>
RESULTS

The results were analyzed using two separate repeated-measures analysis of variance (ANOVA) tests with Huynh-Feldt sphericity correction as well as a Bonferroni-Dunn multiple-analysis correction. Prior to these analyses, the average proportion correct scores across two runs for each condition were arcsine-transformed. For the first analysis, the transformed proportion correct values were analyzed with retention interval and number of distractors as independent variables. The outcomes of the first analysis indicated, as seen in Figure 1, that there was a significant difference for number of distractors ($F(3,6) = 191.76, p = 0.002564$), but not for retention interval ($F(2,4) = 0.66, p = 0.503761$). For the second analysis, the transformed proportion correction values for only the conditions containing distractors were analyzed with condition (see Table 1) as the independent variable. The outcomes of this analysis indicated that there was a significant difference by condition ($F(7,14) = 15.39, p = 0.004677$). Post-hoc tests results ($\alpha = 0.05$) indicated that the performance in the different conditions which contrasted only in background type (i.e., conditions 2 vs. 8 & 4 vs. 6, see Table 1) differed significantly from one another and that performance in the modulated background conditions generally was poorer than that in the unmodulated background conditions (see Figure 2).

FIGURE 1. Group mean performance at each retention interval as a function of the number of non-target background stimuli.

FIGURE 2. Group mean performance and standard error per condition collapsed across retention interval duration.
**FIGURE 3.** Individual mean performance as a function of the number of non-target background stimuli. Individual listener memory span measures are indicated in the figure legend.

**DISCUSSION**

The present results provide measures of the presumed influence of FM-feature detection upon the ability of a listener to compare (i.e., discriminate differences between) two fields of auditory stimuli separated in time for various target and background configurations. Performance in the tasks was heightened substantially in conditions favorable to the influence of FM-feature detection. That is, performance in unmodulated backgrounds was significantly better than in modulated backgrounds (see Figure 2). This finding is comparable to that reported by Cusack and Carlyon (2003) who evaluated the ability of a participant to detect a target stimulus in the presence of multiple background stimuli within a single auditory field containing FM or unmodulated background sounds. They found that FM tones are detected more easily in a field of pure tone stimuli than vice versa and that the number of background sounds influences performance. Similarly, the outcomes of the present study revealed that discrimination performance in unmodulated background conditions is better than in modulated backgrounds and decreased as the number of background stimuli increased (see Figure 1). Performance, however, was not dependent upon the length of the retention interval between the standard and comparison windows. Lastly, individual listener performance was evaluated as a function of the number of background stimuli with regards to the participant’s working memory span with no clear trend evident for the data collected to date. Overall, the present study found that FM-feature detection influences discrimination performance as a function of the number and modulation state of the background stimuli.

**REFERENCES**