J Am Acad Audiol 7: 346–357 (1996)

Detection and Recognition of Octave-band Sound Effects

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Abstract

The goal of this study was to determine whether selected sound effects that are spectrally limited to an octave band width could be used as alternative stimuli to pure tones when testing children and other special populations. The uniqueness of octave-band sound effects is that they retain the natural character of everyday sounds while providing frequency-specific information about hearing sensitivity. In this study, 20 normal-hearing adults were asked to detect and recognize octave-band filtered musical and environmental sounds presented in quiet and in multitalker noise. Detection and recognition thresholds for the filtered sound effects were compared with respective pure-tone thresholds obtained at 250, 500, 1000, 2000, and 4000 Hz for the same subjects. Results indicate that filtered sound effects are a promising alternative to pure-tone stimuli for use in audiometric tests. Applications and limitations of filtered sound effects as test stimuli for testing children and adults are discussed.

Key Words: Detection, recognition, sound effect stimuli

Pure-tone audiometry provides quantitative information about hearing sensitivity at specific test frequencies. Pure tones, however, may not be the most appropriate stimuli for all listeners and for all testing situations. For example, young children have notoriously limited attention spans for pure tones. Such signals are unfamiliar and meaningless to most children, since they are not commonplace in the everyday listening experience (Miller and Polisar, 1964). When evaluating children and clients with a short attention span, audiologists have a limited amount of time available for collecting useful and accurate information about hearing sensitivity (Primus, 1988). In addition, children may display invalid pure-tone thresholds due to a lack of cooperation or the inability to listen for pure-tone stimuli at low intensity levels. Thus, although, in many cases, pure-tone thresholds can be obtained, the audiologist must question their validity (Gerber, 1985). To overcome these difficulties, audiologists should have available a wide range of test stimuli that have sufficient familiarity and appeal to hold the listener's attention throughout the duration of the test and allow audiologists to obtain valid threshold estimates (Keaster, 1947; Matkin, 1969).

An alternative to pure-tone test stimuli that provides some frequency specificity is narrow-band masking noise, which is available on clinical audiometers (Myers, 1967; Sanders and Josey, 1970). However, narrow bands of noise are not standardized as test stimuli and are also artificial signals. More importantly, such noises are usually filtered with slopes of only about 12 dB/octave. Thus, an individual with a steeply sloping audiogram may be responding to energy outside of the center frequency, which results in an incorrect assessment of the listener's hearing sensitivity (Sanders and Josey, 1970; Orchik and Mosher, 1975).

Several authors advocated using frequency-modulated (warble) tones as an alternative to pure tones. When frequency deviations are small (1%–3%), elicited hearing thresholds are similar to those measured with pure tones (Stephens

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and Rintelmann, 1978). Warble tones also have a clear advantage over pure tones in soundfield audiometry and, in this respect, are similar to narrow-band noises. However, the advantage of warble tones over pure tones for testing children and special populations has not yet been shown (Robinson and Vaughn, 1976; Orchik and Rintelmann, 1978).

Another common audiometric stimulus used for testing infants and young children is speech. One procedure using a speech stimulus is to call the child's name or have the child point to body parts. Another procedure is to produce a "sh" sound in an attempt to isolate the high-frequency components of speech. While these practices provide more natural stimuli than tonal stimuli or narrow bands of noise, the spectral properties of the sound will vary according to who is producing the speech. In addition, the speech signal is still a broadband stimulus containing energy outside of the frequency bands of interest.

Some authors have suggested that, when a child does not respond to pure tones, audiologists should turn to hearing tests employing sound effects. An example of a commercial "noisemaker kit" developed for such hearing tests is the Downs Hear-Kit.™ According to Northern and Downs (1984), tests with noisemakers will identify 95 percent of normal-hearing children. Although sound effects (e.g., bells, rattles, and other noisemakers) are more natural than pure tones and narrow-band noise (Myklebust, 1954; Ewing and Ewing, 1958), they only provide qualitative information about hearing sensitivity and neglect the frequency- and intensity-specific information critical to the proper diagnosis and remediation of hearing loss.

It could be argued that sounds created by toy noisemakers have *some* concentrations of energy and, thus, provide frequency-specific information. However, the majority of noisemakers produce wide-band sounds spanning several octaves (Bove and Flugrath, 1973). Such sounds cannot provide satisfactory information about frequency-specific properties of hearing. The same criticism can be extended to recorded animal noises, baby cries, and other sound effects that have been used to test the hearing of children and other special populations when pure-tone audiometry was difficult to administer. To become frequency-specific audiometric test signals, sound effects require spectral filtering to eliminate unwanted parts of their spectra.

The concept of filtered natural sounds for audiometric testing was originally proposed by Downs and Doster (1959). Although they reported success in using environmental sounds filtered to 250 to 750 Hz, 1000 to 2000 Hz, and 3000 to 5000 Hz bands for testing young children from 3 to 5 years of age, their research was not expanded to a frequency-specific audiometric test. Following this research line, Downs (1994) patented a hearing test method using filtered human voice in a single-frequency band of 2000 to 4000 Hz.

In 1969, Matkin evaluated hearing in young children (3 to 6 years old) using pure tones and ⅓-octave-filtered environmental sounds centered at 500, 1000, and 2000 Hz. The filtered sounds were attenuated by at least 30 dB when measured 1 octave above and below the nominal test frequency. All children responded reliably to both types of stimuli and demonstrated no difference between thresholds obtained with pure tones and filtered environmental sounds.

Letowski and Rakowski (1970) advanced the concept of audiometry based on octave-filtered sound effects as audiometric stimuli. Specifically, they developed a test that used octave-band natural sounds with center frequencies ranging from 125 through 1600 Hz. All selected stimuli were 100 percent recognizable by children with normal hearing. The test contained two sets of sound effects developed for two age groups: 0.5- to 3-year-old children (test 1) and 3- to 6-year-old children (test 2). Test 1 included such sound effects as a dog barking, baby crying, spoon rattling in a mug, and drum beating. Test 2 included sounds made by a train, a cuckoo, a sheep, keys, castanets, church bells, etc. All sound effects were recorded on magnetic tape in several randomizations. Due to the difficulties with repeating individual sounds at various levels and with administering a test recorded on magnetic tape, the described test had not been intensively used.

In addition to threshold audiometry, the application of sound effects as stimuli in hearing evaluations has been extended to suprathreshold audiometric tests. Finitzo-Hieber et al (1980) developed the Sound Effects Recognition Test (SERT) for evaluating hearing-impaired and nonverbal children. The SERT is intended as a measure of recognition rather than hearing sensitivity. Finitzo-Hieber et al (1980) reported that some children who were unable to understand speech could identify sound effect stimuli relatively well. Recognizing the importance of frequency-specific test stimuli, Finitzo-Hieber et al (1980) selected sounds on the basis of their frequency content. Again, however, frequency-specific information was lost due to the dominant wideband characteristic of sound effects used in the test.

The most important feature of filtered sound effects as audiometric stimuli is that they can be used both with conventional audiometry and with various forms of operant-conditioning audiometry, including visual reinforcement audiometry (VRA), conditioned play audiometry (CPA), and tangible reinforcement operant conditioning audiometry (TROCA) (Liden and Kankkonen, 1961; Greenberg et al, 1978; Thompson et al, 1979; Northern and Downs, 1984; Primus, 1988; Kile and Beauchaine, 1991). For example, Thompson et al (1989) compared VRA, CPA, and TROCA procedures and concluded that VRA is the safest procedure to be used with 2-year-old children, since the vast majority of 2 year olds readily conditioned to the task. However, this measured advantage is often compromised by a child's rapid habituation to pure-tone signals. The use of filtered sound effects may increase the total number of valid responses obtained prior to habituation.

Another potential use of octave-band sound effects is in conjunction with picture-type tests. Many audiologists have explored the use of pictures in testing to avoid verbal responses (Kaester, 1947; Myerson, 1947; Myatt and Landes, 1963; Ross and Lerman, 1970; Rintelmann and Lynn, 1983; Sigenthaler and Haspiel, 1966; Sanderson-Leepa and Rintelmann, 1976). Picture-type tests have been used routinely with young children to assess speech discrimination. Such a test medium also could be used to assess detection thresholds for octave-band sound effects. Familiar sounds in combination with familiar pictures should maintain a high level of interest in children, thereby keeping them attentive and willing to respond (Siegenthaler et al, 1966). This type of presentation seems logical as looking at pictures and making sounds with parents is a common activity.

The purpose of the present study was to select a group of octave-band sound effects that can be used as stimuli in various audiometric tests performed at both threshold and suprathreshold levels. Specifically, the objective of the study was to measure detection and recognition thresholds for 25 octave-filtered sound effects presented both in quiet and in multitalker noise. The authors hypothesized that such stimuli could be useful signals in the assessment of both hearing sensitivity and masking properties of various environmental sounds. We believe that the ability to detect and recognize familiar signals in a background of noise is a matter of considerable practical value and should be considered in audiometric testing (see Smoorenburg et al, 1982).

The test population was a group of young, normal-hearing adults. This group was selected for two reasons. First, positive results with an adult population were sought before extending this study to children and other special populations. According to Matkin (1969), a major shortcoming of studies advocating the use of complex stimuli with children is that normative threshold data for an adult population were not established initially. Second, the need for complex, nonverbal audiometric stimuli for use with adults has been expressed by the United States Department of the Army and various nonprofit organizations that provide screening tests at schools or other audiologic services in underdeveloped countries (e.g., the Jeddah Institute for Speech and Hearing and the United States Peace Corps).

METHOD

Subjects

Twenty subjects, 18 to 43 years of age (5 males and 15 females; mean age of 25.3 years, standard deviation of 7.49 years) participated in the study. The study required 2 hours to complete. Subjects were paid volunteers. Each subject had normal hearing, bilaterally, from 250 through 4000 Hz, in octave steps (<20 dB HL re: ANSI, 1989).

Test Stimuli

Subjects listened for either pure tones or filtered sound effects presented in quiet or in background noise. The pure-tone stimuli (250, 500, 1000, 2000, and 4000 Hz) were 1000 msec in duration and shaped on and off by 10-msec cosine-squared ramps. The sound effects were various animal, instrumental, and environmental sounds from compact disc sound libraries (Network Music™ and Sound Ideas®). Each sound was octave-band filtered (Bruel and Kjaer Octave Filter 1613, with a 25 dB/octave slope) at either 250, 500, 1000, 2000, or 4000 Hz. Selected sound effects and their octave-band center frequencies are listed in Table 1. The duration of sound effects ranged from 1.2 to 3.9 seconds. The background noise used in this study was a 20-voice multitalker noise (Frank and Craig, 1984) presented at 60 dBA.

Table 1 List of 25 Sound Effects and Their Octave-band Center Frequencies Used in This Study

Sound Number	Sound Name*	Center Frequency (Hz)
1	*Airplane* passing	250
2	*Baby* crying	2000
3	*Bird* singing	2000
4	*Carhorn* sounding	1000
5	*Cat* meowing	2000
6	*Clock* chiming	1000
7	*Cow* mooing	500
8	*Coyote* howling	500
9	*Cricket* chirping	4000
10	*Cuckoo clock* sounding	1000
11	*Dial*ing a telephone	2000
12	*Dog* barking	1000
13	*Drum* beat	500
14	*Frog* croaking	1000
15	*Glass* shattering	4000
16	*Phone* ringing	2000
17	Baby *rattle* shaking	4000
18	*Rooster* crowing	2000
19	*Siren* wailing	1000
20	*Sonar* blipping	500
21	*Thunder* cracking	250
22	*Train* passing	250
23	*Trumpet* charging	2000
24	*Twang*ing harp	2000
25	Referee *whistle*	2000

*Italicized words identify names of the sound effects listed on the computer display. These names are used throughout the text.

Initially, a group of 33 sound effects was selected as potential test signals for use in this study. Individual sound effects were recorded, temporally edited, and then octave band-pass filtered. The center frequency of the octave-band filter was selected to maximally preserve the naturalness of the sound effect under the filtered condition. All 33 sound effects were subsequently presented to a group of 10 listeners for identification. Of the 33 tested sound effects, 25 yielded no identification errors and were chosen as test stimuli for this study.

Instrumentation

Test stimuli were either digitally generated (pure tones) or recorded (sound effects) using a Tucker-Davis Technologies (TDT) System II Signal Processing System (16-bit A/D converter, 10 kHz sampling rate), CSRE 4.2 (Computerized Speech Research Environment, version 4.2) software, and a Gateway 2000 AT 80486/33C personal computer. Multitalker noise (Auditec CD 1) was recorded and played from magnetic tape using a Nakamichi MR-1 cassette deck. Signal control, delivery, and data collection were under computer control through custom written software (PSU31). Stimuli were converted to analog form using a 16-bit D/A converter (TDT DD1) and delivered through a programmable attenuator (TDT PA4) and mixer-amplifier (TDT SM3) to an ER-1 insert earphone equipped with a TIP-50 eartip. (The ER-1 insert earphone simulated listening in a sound field with a natural ear canal pathway.) The nontest ear was occluded with an EAR™ foam earplug. During the tests performed in noise, the multitalker noise was directed from the cassette deck through the mixer-amplifier to the same insert earphone. All testing was performed monaurally for the subject's preferred ear. Routine calibration of the equipment was performed periodically throughout the experiment using a B&K sound level meter (SLM) 2231, B&K adapter UA0122, B&K 4134 pressure microphone, and Zwislocki coupler. The signal-to-noise ratio of the recorded pure tones and octave-band sound effects was greater than 60 dB (ANSI, 1989).

Procedure

Testing was conducted at the U.S. Army Research Laboratory in a listening room having ambient noise levels suitable for soundfield testing (ANSI, 1991). The following hearing thresholds were obtained for each listener:

1. pure-tone detection thresholds for 250, 500, 1000, 200, and 4000 Hz in quiet;
2. pure-tone detection thresholds for 250, 500, 1000, 2000, and 4000 Hz in noise;
3. sound effect detection thresholds for 25 filtered sounds in quiet;
4. sound effect detection thresholds for 25 filtered sounds in noise;
5. sound effect recognition thresholds for 25 filtered sounds in quiet; and
6. sound effect recognition thresholds for 25 filtered sounds in noise.

Each subject was tested individually. During testing, the subject sat in front of a computer terminal used to provide visual cues to the occurrence of a trial interval and to collect subject responses. Diagrams of the display for the detection and recognition task are shown in Figures 1 and 2, respectively.

During the detection task, the subject followed instructions on the screen (*Listen* or *Respond*) and responded by clicking the mouse

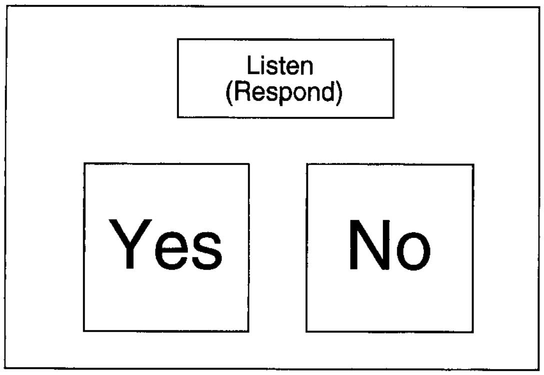

Figure 1 Response screen for the detection task. The top window displayed instructions to the subject (i.e., *Listen* or *Respond*). Two response fields (*Yes* and *No*) were always present on the screen. The subject used a mouse to indicate whether the stimulus was detectable.

button on the appropriate response field (*Yes* or *No*) according to whether the subject heard the sound or not. An adaptive threshold procedure was used to determine detection thresholds for both pure-tone and sound effect stimuli (Pentland, 1980; Lieberman and Pentland, 1982). Presentations of the test stimuli varied over a 60-dB range centering around an estimated threshold value for each sound effect. Determination of each detection threshold began by presenting a test sound at a level thought to be clearly audible to the subject (i.e., approximately 20 dB above the actual threshold). Following every subject response, a maximum-likelihood function and the next stimulus presentation level were computed. Maximum and minimum step size was limited to 20 dB and 1 dB, respectively. The computer program was set to estimate the 50 percent detection point on the psychometric function. Each stimulus (pure tones and filtered sound effects) was presented 15 times before the computer moved on to the next sound, indicated by the words *New Sound* presented on the monitor. After all five pure tones had been tested, one randomly selected pure tone was retested. After all 25 sound effects were presented, a random selection of 5 sound effects was retested.

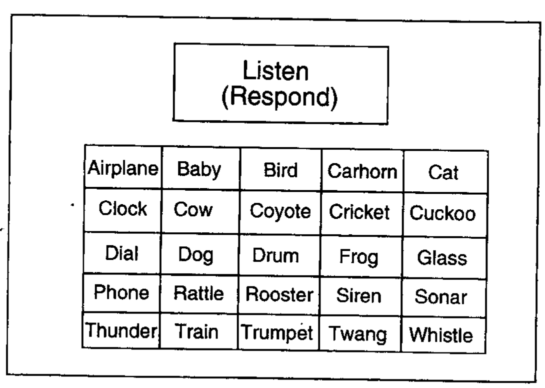

Figure 2 Response screen for the recognition task. The top window displayed instructions to the subject (i.e., *Listen* or *Respond*). The lower window displayed the names of all filtered sound effects. After each presentation, the subject used a mouse to indicate the sound effect that was presented.

During the recognition task, the subject was asked to identify sounds by clicking the mouse button on one of the 25 response fields on the screen (see Fig. 2). Each threshold determination task started by presenting a filtered sound at a level 6 dB less than the subject's established detection threshold for the sound. After each response, the sound level was increased by 2 dB and presented again. This cycle was repeated until the subject correctly identified the sound at three consecutive presentation levels, with recognition threshold defined as the level of the first correct response. Five sound effects were randomly retested after each sound had been presented once.

Each task was presented both in quiet and in noise. The detection task was always presented before the recognition task. Noise and quiet conditions were counterbalanced. The order of the sound effects was randomized for each task and subject.

RESULTS AND DISCUSSION

Threshold of Detection

Mean detection thresholds for the pure tones and sound effects presented in quiet and 60 dBA noise are shown in Table 2 and Figures 3 and 4. Mean pure-tone detection thresholds are represented on both graphs by dashed lines. The detection thresholds for the filtered sound effects are expressed in dB SPL and measured as the maximum rms value for a given sound presented at threshold level. Detection thresholds for sound effects filtered at the same octave frequency were typically within 4 dB of each other, except for sound effects that had their peak energy at 2000 Hz. This occurred in both the quiet and noise conditions. Larger deviations at other frequencies were observed for *thunder* (250 Hz), *drum* (500 Hz), *carhorn* (1000 Hz), and *cricket* (4000 Hz). Standard deviations for the detection task ranged from 4.4 (*coyote*) to 8.4 dB (*frog*) in quiet and from 2.6 (*drum*) to 11.5 dB

Table 2 Detection Threshold Data in Quiet ($_q$) and in Noise ($_n$)

Sound Name	*Mean$_q$*	*Median$_q$*	*Range$_q$*	*SD$_q$*	*Mean$_n$*	*Median$_n$*	*Range$_n$*	*SD$_n$*
Airplane	19.9	19.3	9.9–35.7	6.2	36.2	36.3	27.6–43.8	3.6
Baby	12.2	13.4	0.5–22.7	5.4	32.4	32.2	24.6–38.8	3.4
Bird	13.4	13.8	−0.1–21.9	4.8	32.2	35.0	0.3–39.1	8.8
Carhorn	5.4	5.3	−0.7–14.2	4.4	23.9	24.4	−0.8–30.1	8.7
Cat	14.8	15.5	8.1–23.4	4.4	36.0	35.9	28.1–44.3	3.9
Clock	9.4	8.6	−3.0–30.0	7.4	28.4	29.5	13.5–36.8	6.1
Cow	13.1	13.1	−1.3–26.7	6.2	33.9	34.4	25.2–41.1	4.4
Coyote	12.0	12.2	4.7–21.1	4.4	32.9	32.1	23.0–45.0	4.5
Cricket	10.0	10.1	−4.0–21.9	6.9	17.6	17.5	−4.0–29.8	8.1
Cuckoo	5.9	6.5	−5.1–15.6	5.3	30.1	30.1	26.0–38.9	3.0
Dial	6.6	5.2	−1.0–20.4	5.6	26.0	26.1	15.2–36.0	5.0
Dog	9.4	7.1	−7.9–27.2	8.0	28.2	31.3	12.0–40.5	11.5
Drum	13.8	15.2	−7.1–23.7	7.2	38.2	39.1	29.8–41.2	2.6
Frog	8.3	8.2	−7.5–26.1	8.4	29.1	31.0	11.1–37.5	7.1
Glass	12.5	12.7	−1.3–22.3	5.6	25.1	27.0	4.3–38.4	9.0
Phone	8.1	7.5	−4.9–25.3	7.3	25.4	26.8	7.9–38.2	7.3
Rattle	12.8	14.0	−5.6–22.0	7.8	26.6	27.6	18.2–34.2	5.1
Rooster	5.8	5.8	−6.0–16.5	4.8	26.6	26.6	17.6–33.3	3.9
Siren	8.6	7.3	−3.7–30.1	6.7	27.2	28.0	7.6–33.2	5.2
Sonar	10.0	9.9	−4.7–25.5	6.8	33.9	34.3	13.8–44.0	5.7
Thunder	25.8	27.1	15.1–38.6	6.8	38.2	37.3	30.1–47.6	3.9
Train	18.3	18.3	9.8–28.3	5.2	37.5	37.8	13.3–46.8	5.9
Trumpet	9.2	9.6	−0.1–18.4	5.7	27.6	30.0	3.3–35.6	8.0
Twang	11.5	13.5	−7.4–18.2	6.5	31.9	32.9	18.7–38.1	4.7
Whistle	11.1	11.7	3.1–21.8	5.3	31.2	31.5	26.2–37.8	3.0

Mean, median, and range values are reported in dB SPL (re: 20 μPa). Standard deviations (SD) are reported in dB.

(*dog*) in noise. The typical difference between detection thresholds measured in quiet and in 60 dBA noise was about 20 dB, except for sounds filtered at 4000 Hz (see Table 2). The smaller difference observed at 4000 Hz is believed to be due to the decreased energy of the multitalker noise above 2000 Hz. Test–retest data showed no significant differences in thresholds for either pure tones ($p > .2$) or filtered sound effects ($p > .3$).

Inspection of Table 3 and Figures 3 and 4 indicates that the detection thresholds for a large number of octave-filtered sounds used in

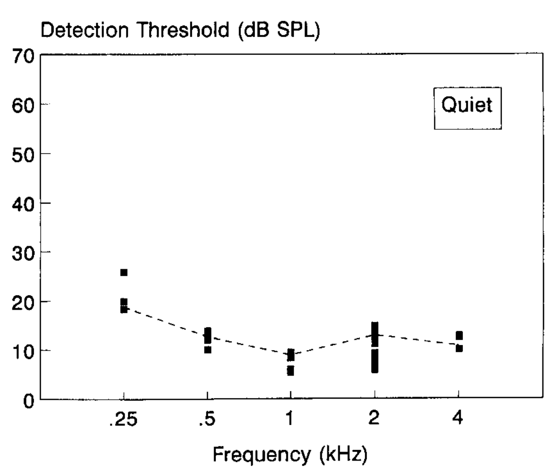

Figure 3 Group mean detection thresholds in quiet. The dashed line represents detection thresholds for pure tones in quiet. Sound effects are displayed according to the center frequency of their filtered band.

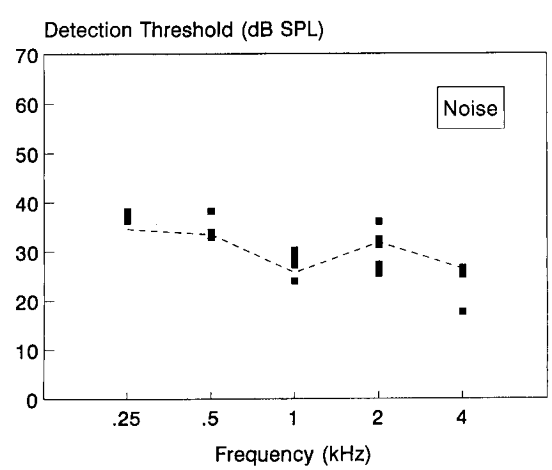

Figure 4 Group mean detection thresholds in noise. The dashed line represents detection thresholds for pure tones in noise. Sound effects are displayed according to the center frequency of their filtered band.

Table 3 Potential Sound Effects for Audiometric Detection Testing

Test Frequency (Hz)	*Stimulus*	*Quiet*	*Noise*
250	Airplane	19.9	36.2
	Train	18.3	37.5
	PT	18.8	34.5
500	Cow	13.1	33.9
	Coyote	12.0	32.9
	PT	12.6	33.4
1000	Clock	9.4	28.4
	Dog	9.4	28.2
	Siren	8.6	27.2
	PT	8.9	25.6
2000	Baby	12.2	32.4
	Bird	13.4	32.2
	Twang	11.5	31.9
	Whistle	11.1	31.2
	PT	12.9	31.7
4000	Rattle	12.8	26.6
	Glass	12.5	25.1
	PT	10.8	26.4

Mean thresholds for the pure-tone (PT) stimuli and selected octave-filtered sound effects are reported in dB SPL. For each center frequency, detection thresholds are reported for both the quiet and noise condition.

this study were similar to hearing thresholds obtained with corresponding pure tones. At each octave frequency, at least two sound effects render detection thresholds within 2 dB (in quiet) and 3 dB (in noise) of hearing thresholds for pure-tone signals. The subgroup of sounds yielding detection thresholds similar to those for pure tones, in both quiet and noise, is listed in Table 3.

Reported similarities between pure-tone thresholds and the thresholds for octave-band sound effects have been previously observed by Matkin (1969) for ⅓-octave filtered sound effects and by Mitrinowicz and Letowski (1965), Simon and Northern (1966), Sanders and Josey (1970), Gengel et al (1971), Cox and McDaniel (1986), and Cohen and Fielder (1992) for narrow-band noises tested on people with essentially flat audiometric configurations. The above similarity seems to indicate that hearing thresholds for complex natural sounds are determined by short-term narrow-band peaks of signal energy rather than by overall sound energy in the transmitted band (Price and Hodge, 1976).

It may be argued that sound effects rendering thresholds similar to those of respective pure tones should be considered good material for developing a frequency-specific audiologic test. Selected sound effects conforming to the above criteria can be stored in the audiometer memory or recorded on a compact disc and used as an alternative to pure-tone stimuli without defining another audiometric zero level for such signals. Note, however, that the octave-band sound effects filtered with 25 dB/octave filters, such as those used in this and other studies, are a possible alternative to pure-tone stimuli only in identifying flat and slightly sloping hearing losses. For the assessment of steeply sloping hearing losses, steeper filtering is required.[1] In general, the narrower the band width and the steeper the filter slope, the better similarity can be obtained between pure-tone and octave-band sound effect thresholds (Orchik and Mosher, 1975). Conversely, the wider the band width and the shallower the slopes, the smaller the difference between detection and recognition thresholds.

Threshold of Recognition

The recognition thresholds for the quiet and noise conditions are shown in Table 4 and Figures 5 and 6. Mean detection thresholds for octave-band sound effects are represented by dashed lines on both figures for reference purposes. The range of standard deviations for the recognition task was 4.5 (*bird*) to 14.8 (*drum*) in quiet and 6.2 (*baby*) to 13.8 (*drum*) in noise. No significant differences between the test and retest recognition thresholds were observed ($p > .3$) for either the quiet or noise condition.

As expected, recognition thresholds for the quiet condition always occurred at a lower level than the recognition thresholds for the noise condition. These differences typically ranged from 17 to 26 dB, except for the sound effects filtered at 4000 Hz. The effect of noise on recognition threshold for sounds filtered at 4000 Hz was less than for those filtered at lower frequencies. Again, this could be caused by decreased energy of the masking noise above 2000 Hz. The highest recognition thresholds occurred regardless of the listening condition for the sound effects filtered at 250 Hz. In addition, these low-frequency sound effects were the most frequently mistaken for other sound effects. These and other frequent substitutions are listed in Table 5. These substitutions usually occurred

[1]A compact disc with selected sound effects that have been octave filtered using greater than 30 dB/octave slope filtering is available from the first author (Ms. Laurie Myers, 1501 Lincoln Way, Suite 211, White Oak, PA 15132).

Table 4 Recognition Threshold Data in Quiet ($_q$) and in Noise ($_n$)

Sound Name	*Mean$_q$*	*Median$_q$*	*Range$_q$*	*SD$_q$*	*Mean$_n$*	*Median$_n$*	*Range$_n$*	*SD$_n$*
Airplane	30.6	27.0	9.9–57.2	13.6	47.4	47.4	19.3–68.0	10.7
Baby	17.9	19.0	2.5–28.7	6.5	37.0	34.9	29.3–53.3	6.2
Bird	18.5	17.8	8.3–25.4	4.5	39.2	36.0	28.0–52.5	6.8
Carhorn	15.5	11.4	–0.7–36.1	9.4	32.6	30.1	3.3–57.3	13.4
Cat	24.2	25.0	10.2–42.0	7.3	47.2	42.7	37.0–67.0	9.1
Clock	21.0	19.4	8.4–39.0	8.3	40.7	40.7	29.0–64.1	10.1
Cow	24.9	25.4	4.0–43.5	9.5	49.9	50.0	35.6–67.8	8.4
Coyote	23.4	20.0	6.1–45.6	11.6	45.4	42.6	30.5–65.1	11.9
Cricket	19.3	18.1	2.3–29.1	7.7	22.5	15.5	12.1–34.4	7.2
Cuckoo	14.5	13.7	0.2–32.9	7.7	38.7	37.7	27.1–55.0	7.6
Dial	12.7	12.6	–4.2–32.4	8.8	39.2	37.9	20.2–56.0	10.5
Dog	18.4	20.3	4.1–29.8	8.0	45.2	43.0	11.6–69.3	12.6
Drum	36.2	38.1	5.8–55.7	14.8	57.4	57.8	11.9–78.6	13.8
Frog	22.7	19.6	10.0–47.1	9.6	46.5	45.9	25.1–61.5	9.9
Glass	22.5	19.6	9.0–42.3	9.3	30.0	30.1	4.2–44.4	10.3
Phone	11.4	11.4	–3.5–26.9	8.9	30.4	28.8	15.9–43.3	7.9
Rattle	26.5	26.6	12.8–42.0	7.5	35.9	36.5	22.5–50.8	8.5
Rooster	8.2	5.2	–4.7–28.2	8.0	33.2	27.7	19.6–56.6	10.7
Siren	17.5	18.2	–0.7–33.1	7.9	37.7	39.0	15.6–52.7	9.3
Sonar	19.2	18.8	6.6–46.1	10.0	47.2	48.0	21.1–69.3	10.9
Thunder	47.5	45.4	30.6–67.1	9.0	61.5	62.0	42.6–72.1	8.4
Train	40.7	35.8	21.8–62.3	10.8	59.9	61.0	30.3–82.8	13.8
Trumpet	14.8	13.1	–0.1–29.9	6.6	35.5	33.8	11.4–62.1	12.7
Twang	25.9	26.8	10.6–39.5	7.4	43.9	41.2	30.7–69.3	9.2
Whistle	18.4	13.7	5.4–43.2	12.0	38.7	36.9	28.6–66.5	8.3

Mean, median, and range values are reported in dB SPL (re: 20 μPa). Standard deviations (SD) are reported in dB.

between the sound effects having either similar temporal pattern or frequency characteristics.

Recognition thresholds obtained in quiet and in noise can serve as guidelines for developing picture identification tests that are frequency specific. In addition, it can be hypothesized that, with young children, we often substitute the recognition threshold for the detection threshold. Frequently, children do not respond to a low-level acoustic stimulation unless they hear a familiar sound, that is, unless they recognize the stimulus. Thus, octave-band filtered and easily recognizable sound effects may render stable and simple-to-obtain thresholds

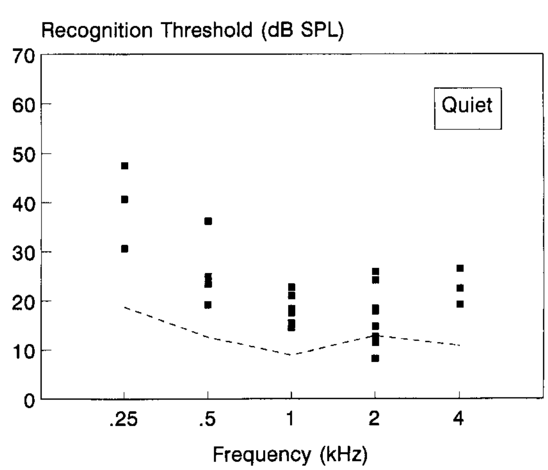

Figure 5 Group mean recognition thresholds in quiet. The dashed line represents detection thresholds for the filtered sound effects in quiet. Sound effects are displayed according to the center frequency of the filtered band.

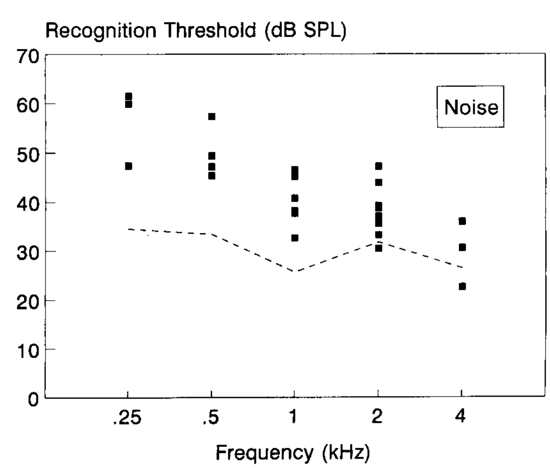

Figure 6 Group mean recognition thresholds in noise. The dashed line represents detection thresholds for the filtered sound effects in noise. Sound effects are displayed according to the center frequency of the filtered band.

Table 5 Common Recognition Substitutions

Presented Sound	*Response*
Baby	Cat
Cat	Bird, coyote
Cuckoo	Twang
Dog	Train
Drum	Thunder, train
Glass	Rattle
Coyote	Cat, cow
Thunder	Airplane, train
Trumpet	Rooster

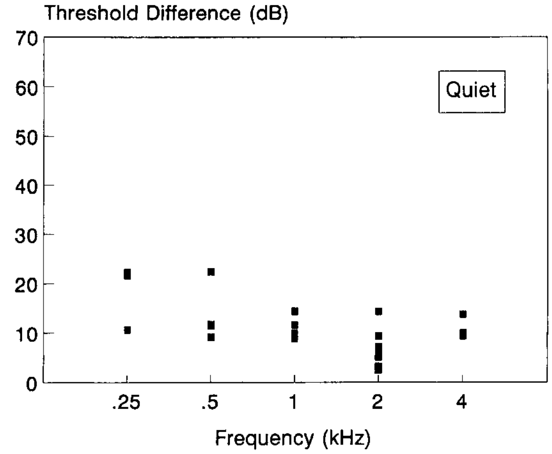

Figure 7 Differences between mean detection and recognition thresholds in quiet. Sound effects are displayed according to the center frequency of the filtered band.

that could be used, in some cases, instead of less-defined and less-repeatable pure-tone hearing thresholds. For example, octave-band filtered sounds may be the signal of choice for hearing screening tests of preschool-aged children. Such screening tests employing pure tones have limited diagnostic value.

Difference Between Detection and Recognition Thresholds

The differences between the mean detection and recognition thresholds for individual sounds are shown in Table 6 and Figures 7 and 8. Differences between detection and recognition of the same sound ranged from 2 to 4 dB (*phone, rooster*) to 22 to 24 dB (*drum, thunder, train*) in both quiet and noise. The size of these differences was generally inversely proportional to the center frequency of the octave-filtered sound. The largest differences were observed at low frequencies and the smallest at high frequencies. The difference between the detection and recognition threshold was always larger for the noise condition than the quiet condition, except for some sounds filtered at 2000 and 4000 Hz. The different behavior of these sounds seems to be caused by the decreased energy of the masking noise above 2000 Hz.

Table 6 Threshold Differences Between Detection (D) and Recognition (R) Thresholds in Quiet ($_q$) and in Noise ($_n$)

Sound Name	*Detection$_{n-q}$*	*Recognition$_{n-q}$*	*R-D$_q$*	*R-D$_n$*
Airplane	16.3	16.8	10.6	11.1
Baby	20.1	19.1	5.6	4.6
Bird	18.7	20.7	5.1	7.0
Carhorn	18.5	17.1	10.0	8.6
Cat	21.2	23.0	9.3	11.2
Clock	19.0	19.7	11.6	12.3
Cow	20.8	25.0	11.7	16.0
Coyote	20.9	21.9	11.4	12.4
Cricket	7.6	3.1	9.3	4.8
Cuckoo	24.2	24.2	8.8	8.5
Dial	19.4	26.4	6.4	13.1
Dog	18.8	26.8	9.0	16.9
Drum	24.4	21.2	22.4	19.2
Frog	20.7	23.7	14.4	17.4
Glass	12.5	7.4	9.9	4.8
Phone	17.2	18.9	3.2	4.9
Rattle	13.8	9.3	13.7	9.2
Rooster	20.7	24.9	2.4	6.6
Siren	18.6	20.1	8.9	10.4
Sonar	23.9	28.0	9.1	13.2
Thunder	12.3	14.0	21.6	23.3
Train	19.1	19.1	22.3	22.4
Trumpet	18.4	20.7	5.5	7.8
Twang	20.3	18.0	14.3	12.0
Whistle	20.0	20.3	7.2	7.4

Tabled values are in dB SPL (re: 20 μPa).

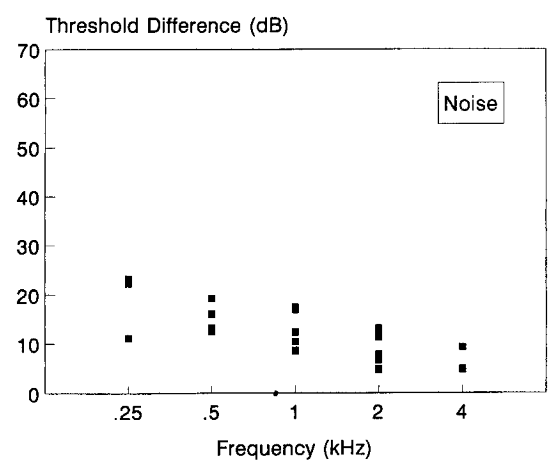

Figure 8 Differences between mean detection and recognition thresholds in noise. Sound effects are displayed according to the center frequency of the filtered band.

Small differences between detection and recognition thresholds may be considered a criterion for selecting filtered sound effects for both threshold and suprathreshold audiometric testing. Large differences between these thresholds may indicate stimuli that can be easily affected by noise and other interferences during a recognition task. In addition, a small difference between both thresholds can be an indicator that the sound effect is familiar to the listener. Such a small difference also points toward a relatively uniform long-term average spectrum within the operational band. While a narrowband peak of energy may be responsible for absolute detection of the signal, especially for normal-hearing adult subjects, the overall octave-band energy is needed for sound identification (Price and Hodge, 1976). Most of the sound effects used in this study could not be identified by untrained subjects when the sounds were limited with a ⅓-octave band width, even if they were presented at a high suprathreshold level.

CONCLUSIONS

Reported results indicate that octave-filtered sound effects can be reliably detected and easily identified by young, normal-hearing adults. Most of the octave-filtered sounds used in this study seem to be appropriate for hearing threshold audiometry. In addition, comparison of detection thresholds for pure tones and octave-filtered sound effects indicate that several of such sound effects render detection thresholds that are very similar to pure-tone thresholds at the appropriate center frequency. Therefore, proper selection of sound effects may facilitate the use of audiometers calibrated for pure tones without recalibration.

To be useful as test stimuli for listeners with a wide range of audiometric threshold configurations, the octave-band sound effects must have sharp spectral skirts. The filtered sound effects used in this study were octave filtered with a 25 dB/octave slope filter. With this amount of filtering, thresholds for normal-hearing, flat, and gently sloping audiometric configurations should be equivalent to thresholds obtained with pure-tone stimuli. To obtain thresholds similar to pure-tone thresholds for listeners with other audiometric configurations, the octave-band sound effects need to be filtered with a steep filter slope. Otherwise, listeners could be responding to energy outside of the test octave, which produces erroneous thresholds and an incorrect assessment of hearing sensitivity. However, it must be kept in mind that octave-band sound effects will be examining the sensitivity and integrity of wider areas of the basilar membrane than pure-tone stimuli. Depending on the application, this can be either a strength or a limitation of filtered sound effect testing (Cox and McDaniel, 1986).

Data obtained for recognition thresholds at 500, 1000, 2000, and 4000 Hz indicate that several of the sound effects can be reliably recognized at levels of 10 dB or less above the detection threshold. Such sound effects seem to be effective stimuli for audiometric testing of children and adults with special needs. The sound effects filtered at 250 Hz required much higher presentation levels (re: detection threshold) than all other sound effects. Such sound effects may be clearly heard and still easily confused with other sound effects and should be avoided. Either more research needs to be done to find low-frequency sound effects that have low recognition-detection threshold differences or this octave band needs to be eliminated from consideration.

Due to the widespread use of compact disc recordings, which allow for instant access to any sound track, and the possibility of storing audio signals in the audiometer's ROM (read only memory), the use of filtered sound effects has become practical. In other words, the audiologist can quickly retrieve the filtered sound effects in real time rather than being hindered by a specific order of presentation, as with tape-recorded stimuli. Filtered sound effects may provide the audiologist with alternative stimuli that potentially can be useful (a) in both threshold and suprathreshold tasks, (b) with conventional audiometry and with various forms of operant-conditioning audiometry, and (c) in conjunction with pictures when the audiologist wants to avoid or is unable to obtain verbal responses from the listener. In conclusion, the thresholds obtained in both the quiet and noise condition support the applicability of octave-band filtered sound effects in modern audiometry and sound detectability studies. However, further research is needed to verify whether presented findings can be generalized to populations other than the one used in this study.

Acknowledgments. This work was supported by the Human Research & Engineering Directorate of the U.S. Army Research Laboratory, Cooperative Research and Development Agreement 9403-A-C356. Research was presented in poster format at the 127th Meeting of the Acoustical Society of America, Cambridge, MA, June

1994. The authors would like to acknowledge the time and patience of Jessica Gothie for her work on the software for this experiment.

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