U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

People Saving People
http://www.nhtsa.dot.gov

DOT HS 808 535

November 1995

Technical Report

Multiple Attribute Evaluation of Auditory Warning Signals for In-Vehicle Crash Avoidance Warning Systems

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 808 535		
4. Title and Subtitle Multiple Attribute Evaluation of Auditory Warning Signals for In-Vehicle Crash Avoidance Warning Systems		5. Report Date 11/95 6. Performing Organization Code
7. Author(s) Tan, A.K., and Lerner, N.D.		8. Performing Organization Report No.
9. Performing Organization Name and Address COMSIS Corporation 8737 Colesville Road - Suite 1100 Silver Spring, Maryland 20910		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTNH22-9 1 -C-07004
12. Sponsoring Agency Name and Address Office of Crash Avoidance Research National Highway Traffic Safety Administration U.S. Department of Transportation Washington, DC 20590		13. Type of Report and Period Covered Technical Report 14. Sponsoring Agency Code

15. Supplementary Notes

NHTSA COTR: Michael Perel, NRD-52

16. **Abstract**

This research was directed at optimizing the auditory warnings that may be used in future crash avoidance warning applications. There is a need to standardize such warnings, so that they retain immediacy of meaning across various vehicles, situations, and hazards. The current findings contribute to an empirical basis upon which such decisions can be made, so that an effective warning stimulus is ensured. The research included the following sequence of steps: it identified key attributes of auditory warning signals; established relative importance weightings for each of those attributes through expert ratings; collected subjective ratings 'or each attribute for a set of potential crash avoidance warning sounds through a laboratory experiment; applied the weightings to the subjective ratings to evaluate each sound; and identified a most-promising subset of sounds, based on the findings. The; experimental study was successful in identifying four acoustic signals as preferred over 22 others for in-vehicle application. Findings for voice message warnings were less clear, since no voice message stood out as clearly better.

17. Key Words		18. Distribution Statement	
ITS, crash avoidance warnings, alarms			
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 Reproduction of completed page authorized

TABLE OF CONTENTS

TABLE OF CONTENTS
(Cont'd)

TABLE OF FIGURES

TABLE OF TABLES

BACKGROUND

The purpose of this study was to define acceptable candidate sounds for use as imminent crash avoidance warnings in vehicles. The study addressed the important attributes of such warnings, then measured those attributes among a collection of possible alternatives. As in-vehicle warning systems become more commonplace, it will become important to standardize the warning sounds employed. Furthermore, the Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices (COMSIS, 1993) strongly argued for the adoption of a single unique warning sound that would be used for all imminent crash warning situations. Since there is virtually an infinite number of potential stimuli, the approach of this study was to apply the evaluation criteria to a varied set of reasonable warning sound alternatives, in order to derive most-promising candidates. Because both acoustic (non-verbal) and spoken voice warnings might be implemented in vehicles, the study evaluated candidate stimuli of both sorts.

Due to the number of potential crash avoidance warning devices, the possible combinations of such devices in a vehicle, and the range of other potential in-vehicle warnings and concurrent communications, it is not feasible to specify unique auditory warning signals for each device that are both meaningful and immediately discriminable from one another, particularly for untrained users. In addition, drivers may rarely encounter some types of warnings, or particular warning devices may not be in all vehicles, so that coding a warning for each device will add to confusion and delayed responding. In fact, human factors guidelines recommend severely restricting the number of coded warning displays, particularly acoustic, to a maximum of perhaps four. This is true even in cockpit or control room applications, where operators are much more highly trained than drivers; and, even for these applications, there has been a tendency to forget the meaning of signals over time.

The approach to these concerns in the aviation environment has been to use an attention or master alerting signal supplemented by secondary displays, the latter indicating the exact nature of the alarm. Since the number of warning displays on a flightdeck is high, these displays are often grouped based on the system being monitored. The master alerting signal draws attention to these grouped displays and further information may be conveyed by visual means. An example of such an arrangement would be an engine fire alerting system on the flightdeck. For such a system a unique alarm for “engine fire” is sounded and visual indicators, located together on a panel, indicate where the engine fire has been detected. To improve the speed of determining the location of the fire, the indicator lights may also be located within an outline of a plan view of the aircraft.

The Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices suggests a similar approach for presenting auditory warnings in vehicles. As such, a single alerting alarm should be used to draw attention to the potential hazard(s) detected by the crash avoidance warning system. Specifically, it is recommended that a conspicuous and unique warning signal be created that will provide the driver with information that an imminent crash situation exists and that an immediate corrective action must be made. This unique signal will be used as the master alerting sound for all crash avoidance warning devices installed in a particular vehicle.

Since the recommendation that a single unique warning be selected for all crash avoidance warning device actuations, the need to distinguish device activation and provide direction or type of hazard simultaneously must be accomplished through visual displays, haptic displays or by manipulating the perceptual location or source direction of the warning. The latter form of directional information portrayal will be discussed and investigated in a second experiment. As a result, basic features of the auditory warning will always be present that will be uniquely reserved for imminent crash avoidance warnings; however, localization cues within the "imminent" crash avoidance warning might be used to indicate the nature or location of the hazard. It is anticipated that this additional component will help to reduce the time required to respond effectively to the crash hazard.

METHODOLOGY

The study described in this document was a three part investigation that evaluated twenty six different warning sounds as potential candidates for an in-vehicle collision avoidance warning. The three parts of the investigation were as follows:

1) Questionnaire mailing to rate attributes of auditory warnings
2) Selection and development of candidate warnings
3) Multiple Attribute Evaluation (MAE) of candidate warnings.

The third part of the investigation, the MAE, provided the framework for evaluating the candidate warnings using expert opinions (questionnaire results) and end-user acceptability (i.e., through a laboratory experiment). These portions of the investigation provided the expert opinions and the candidate warnings, respectively, that were used in the MAE (these will be discussed in the MAE section to follow). Each of these three parts are fully detailed in order; however, the MAE procedure will be introduced first, to provide the motivation and framework for the questionnaire and candidate warning creation discussions. A detailed description of the MAE experiment will then be presented.

INTRODUCTION TO THE MAE TECHNIQUE

The research plan recognized that auditory warnings must be evaluated on a number of different dimensions, and that an important factor in identifying an optimal warning sound for crash avoidance warning devices is to realize that sounds have multiple attributes. In some cases these attributes may even be counter productive (i.e., attention gathering vs. startling). Consequently, this study utilized a Multi-Attribute Evaluation (MAE) technique to assess each candidate warning.

The MAE procedure provides a method for screening a large set of candidate signals, eliminating those that appear least likely to perform well, and pointing out those that are most likely to perform well. The method does not actually measure the perceptual and behavioral responses of drivers to an unexpected signal. Such behavioral evaluations, which are much more time consuming and costly, should be done at a later stage with a reduced set of most-likely candidates. The success of the method depends upon the assumption that research participants are able to provide reasonable subjective judgments of each attribute. While this is a reasonable assumption, the judgments and weightings should be viewed as approximations. The technique thus provides an efficient and reasonable method that permits a general screening or ordering of alternative stimuli. It should not be viewed as a precise estimate of actual performance.

This methodology requires two key components. The first is defining and weighting the key attributes of the auditory warnings to be evaluated This can be done in a number of ways. In this study, a questionnaire of expert judgement was used to define and provide weights for the attributes. This questionnaire was sent out to key individuals within the human factors and Intelligent Transportation Systems (ITS) communities to assess the importance of various attributes on the effectiveness of auditory crash avoidance warnings. The second component is to score the alternative warning signals on these attributes. In the present study, this was accomplished through a set of psychometric responses by participants drawn from the general population. This latter component was achieved through execution of the MAE evaluation in a laboratory setting.

In summary, the MAE accomplishes its two key objectives by defining the criteria on which the auditory warnings are to be evaluated, assigning weights to those criteria, developing a candidate list of auditory warnings, scaling and evaluating those warnings on the criteria, and combining the resultant numbers into a total score. Auditory warnings can then be compared and selected based on the overall total score. The process requires the five primary steps shown below:

(1) Define evaluation attributes
(2) Weight evaluation attributes
(3) Define alternative stimuli
(4) Scale and score alternatives on attributes
(5) Calculate a utility score for each alternative.

These five steps were used to evaluate the warning signals in this study. Each of these steps are detailed in the following sections.

Definition and weighting of evaluation attributes

During the earlier tasks of this project, involving literature review and the development of draft human factors guidelines, several key features of good warning systems were identified. This list of attributes was used as a starting point for generating the set of attributes used to evaluate the warnings. The completed list of attributes and associated definitions were then presented to human factors experts in NHTSA, NHTSA contractors working in crash avoidance, and other human factors experts in the ITS community, to be evaluated and ranked according to importance. The participants in the questionnaire weighting were asked to rate each of the attributes on a scale of 1 to 10 on its importance as an attribute of crash avoidance warning signals. An average rating was then calculated based on the participants responses. These ratings were then used as the expert weighting for the attributes in the MAE laboratory experiment. A further discussion of the attributes selected can be found in the Questionnaire Mailing section of this document.

Define alternative warning signals

This step determined an initial set of twenty-six warning sounds that met broad guidelines for acceptability based on research and standards. The list was developed by sampling existing warning indicators, and selecting several others based on the physical characteristics of preferred warning indicators. A detailed discussion of the selection process and characteristics of the final stimuli is provided. The list of twenty-six alternatives was then evaluated using the MAE technique to select three top voice warnings and three top acoustic warnings.

Scale and score warning sounds on attributes

The scaling of sounds was accomplished through a laboratory experiment where participants were asked to rate each alternative warning sound on each attribute. The method is detailed in the MAE section, and constitutes the primary data collection procedure of the study. The data collected in this experiment were then used to calculate a utility score (total score) for each alternative.

Calculate a utility score for each warning sound

The purpose of the prior four steps was to determine six alternatives that are possible candidates for use as an imminent collision avoidance warning. The major calculation involved the matrix shown in Figure 1. In this figure, each of the twenty-six warning sounds (rows) received a rating based on each of the ten attributes (columns) in the experiment. The average rating for each attribute across participants was then input into the matrix. The utility score, or combined weighted average score, for each warning sound was calculated by multiplying each attribute rating for that warning by the respective expert weighting (shown in the second row of the matrix) and then adding the weighted averages across attributes. The outcome of these calculations yielded the utility score or combined weighted score for each warning sound that can be found in the far right column. Additional statistical analyses were also performed to investigate differences in ratings due to sound, age, and background noise effects. The experimental design and complete analysis of the MAE are discussed later in this document.

ATTRIBUTE	ANNO	APPR	DISC	EXP	MEAN	MUSI	RESP	CONS	STAR	URG	WEIGHTED SCORE
EXPERT RATING	-4.37	5.66	9.23	7.63	9	2.26	8.63	9.43	-7.6	8.8	
ALTERNATIVE											
1	6.28	5.72	6.63	6.50	5.94	2.72	6.59	6.59	6.53	6.22	299.45
2	4.44	5.06	4.44	4.38	4.22	3.31	4.56	5.06	4.75	4.53	219.93
3	4.69	4.66	4.97	4.53	4.19	3.03	4.78	5.25	4.88	4.50	224.15
4	3.97	4.69	5.09	4.47	3.97	4.69	4.63	5.31	4.66	4.09	227.22
5	5.38	5.81	5.94	6.06	5.25	4.25	5.69	6.22	5.97	5.53	278.34
6	5.16	4.47	4.75	4.50	4.19	3.06	4.53	4.69	4.66	4.53	213.32
7	5.59	4.81	5.31	5.13	4.53	2.59	5.03	5.69	5.63	4.69	233.12
8	5.28	5.59	6.34	5.94	5.47	4.22	6.13	6.22	6.13	6.09	289.73
9	4.38	4.63	5.19	4.91	4.25	3.47	4.81	5.09	4.78	4.56	231.83
10	5.28	5.63	6.25	5.88	5.66	3.75	6.13	6.13	6.03	5.84	287.03
11	4.16	4.47	5.00	4.47	3.75	4.56	4.31	5.19	4.91	3.94	214.93
12	5.00	4.56	5.56	4.88	4.19	4.41	4.63	5.28	5.22	4.81	232.59
13	5.28	4.88	4.63	4.91	4.22	3.34	4.94	5.16	5.53	4.88	222.48
14	3.56	4.69	4.50	4.59	4.38	3.31	4.88	4.97	4.13	4.69	233.31
15	3.59	4.28	4.50	4.34	4.06	3.31	4.44	4.81	3.84	4.41	220.51
16	3.25	4.50	4.34	4.16	3.97	3.41	4.50	4.53	3.72	4.19	216.66
17	3.09	3.91	4.22	3.91	3.56	2.94	4.25	4.25	3.22	3.94	203.05
18	2.53	3.34	3.16	3.09	2.59	2.44	3.31	3.25	2.44	2.91	155.69
19	2.63	3.06	3.00	2.88	2.25	2.66	3.16	3.16	2.41	2.81	145.23
20	3.59	4.44	4.56	4.19	4.19	3.47	4.31	4.63	3.81	4.50	220.55
21	3.13	3.69	3.97	3.81	3.31	3.22	4.03	4.00	3.38	4.16	193.41
22	3.09	3.59	3.56	3.09	3.09	2.78	3.28	3.69	2.41	3.19	170.20
23	3.03	3.28	2.94	2.50	2.50	2.44	2.84	3.09	2.34	2.81	140.14
24	2.56	2.88	2.72	2.41	2.09	2.50	2.78	2.84	2.25	2.41	127.95
25	3.31	3.38	3.31	2.94	2.78	2.50	3.41	3.31	2.78	2.94	153.71
26	5.03	3.38	3.84	3.41	4.03	1.66	4.16	4.47	4.25	3.81	177.91

Figure 1. Sample MAE matrix

QUESTIONNAIRE MAILING

A questionnaire was constructed to determine which attributes are important in conveying the proper meaning of an "imminent" crash warning. The purpose of the questionnaire was to rate the importance of these known attributes (e.g., discriminability, noticeability, etc.) for an in-vehicle collision avoidance warning application. The attributes that were included in the questionnaire encompass several prominent facets of a how a warning sound may be interpreted. The goal for selecting each attribute was to have a set that encompassed as many of the perceptual aspects of the sound as possible, without having too much overlap among attributes. Therefore, the set of attributes were carefully defined to clarify boundaries and to minimize overlap. Table 1 provides a summary description of the initial ten attributes selected for evaluation.

A recruiting form was developed and prospective candidates in the human factors and safety community were contacted by telephone from industry, government, consulting and academia. These candidates were active in human factors, auditory displays, or transportation. The questionnaire was then mailed to the individuals who agreed to complete the questionnaire, as well as to several individuals who could not be contacted by phone. In addition, several individuals received multiple copies in order to circulate the questionnaire to appropriate colleagues. A total of fifty-eight questionnaires were mailed. Thirty-six questionnaires were returned.

The questionnaire consisted of rating and ranking the ten attributes relative to each other (a sample of the questionnaire and accompanying cover letter can also be found in Appendix A). The attribute definitions included in the questionnaire are provided in Table 2 (Note: these definitions are simply edited versions of the definitions appearing in Table 1). Suggestions for additional attributes not included in the questionnaire were also collected, as well as comments. However, only changes to the attribute names and definitions were made based on these comments. New suggested attributes were not added. The revised appear in column three of Table 2. In general, comments reflected that several of the attributes were not mutually exclusive or were ambiguous and, therefore, were difficult to rate or rank. The questionnaire analysis, however, was based on the data returned using the original attribute names and definitions. The reworded definitions were used in the laboratory study portion of the MAE experiment.

Two additional attributes were included on the questionnaire based on their presumed minor significance as warning attributes, to encourage full utilization of the 10 point scale. These two attributes were Musicality and Naturalness--both were rated and ranked in the questionnaire as least important. Five different attribute orderings for the questionnaire were developed to account for ordering effects.

TABLE 1: Summary of auditory warning attributes

ATTRIBUTE 1	DEFINITION
Conspicuity	This attribute measures the extent to which the warning signal stands out from other noises and sounds within the vehicle-a good signal must be heard in all the noise environments in which it will be used. Warning sounds can be made to be conspicuous by several methods including volume, pitch, and sound envelop.
Discriminabiity	This attribute measures the extent to which the warning signal is uniquely identifiable from other sounds within the driving environment. The opposite of this attribute is its confusability with other sounds within the driving environment. These include both in-vehicle sounds such as other warnings, radio and passenger conversation, other vehicle (Navigation aids) and non-vehicle (electronic games) sounds and exterior noises.
Meaning	This attribute measures the ability of the warning to carry the meaning of "imminent crash". That is, does the signal itself contribute to the driver's ability to determine that it is a crash avoidance warning.
Urgency	This attribute measures the ability of the warning to convey the proper sense of urgency, and motivate the driver to respund immediately
Annoyance	This attribute measures the degree to which a warning sound, which by nature must capture the driver's attention, is annoying to the driver. The key issue here is the extent to which the drivers will accept and continue to use a device that utilizes the sound.
Startle	This attribute measures the degree to which the warning sound will startle the driver. While startle itself may not be a problem, the extent to which the driver behaves in an unpredictable manner when startled, or the extent to which the driver delays the response as a result of startle may result in degrading of the warning effectiveness.
Response Compatibility	This attribute measures the ability of the warning to instigate a proper response to the warning.
Experience Compatibility	This attribute measures the existence of relations user's have with the warning to other sounds they might have experienced. For example, a siren or words such as "DANGER" and "CAUTION" may be associated with an emergency warning.
Appropriateness	This attribute measures the compatibility of a warning sound with the vehicle environment. For example, would users clearly object to having their vehicle present a certain type of warning sound.
Localization and Orienting	This attribute measures the degree to which the warning sound can be localized in 3-D sound space, and cause the driver to look in the direction of the sound. This is considered important to this application since a single distinct warning sound is being recommended for all imminent crash warnings.

Questionnaire Tasks

Participants were asked to rate each attribute on a scale from 1 to 10 on how important they felt the attribute was in the design of an "imminent" crash warning for an in-vehicle crash avoidance warning system. A " 1" signified that the attribute was TRIVIAL while a " 10" signified that the attribute was VERY CRITICAL. For the ranking portion of the questionnaire, the MOST CRITICAL attribute of an auditory warning was assigned a rank of " 1 ", the second a "2", and so forth (ranking ties were not allowed). Suggestions for additional attributes were also ranked together with the twelve existing attributes, but were removed from the rankings for data analysis. Consequently, the rankings ranged from 1 to 12.

TABLE 2: Questionnaire and MAE attribute names and definitions

ATTRIBUTE	QUESTIONNAIRE DEFINITION	REVISED MAE NAME AND/OR DEFINITION
Conspicuity	The auditory warning is noticeable within other noises and sounds in the vehicle.	NEW NAME: NOTICEABILITY The sound is readily noticeable among other sounds and noises in a vehicle (i.e., you can easily hear this sound within the vehicle noise).
Discriminability	The auditory warning is uniquely identifiable and distinct from other sounds in the driving environment.	The sound is uniquely identifiable and distinct from other sounds in the driving environment (i.e., sounds such as CB, radio, vehicle instrumentation, conversation, etc.).
Meaning	The auditory warning unambiguously conveys or suggests the meaning of "imminent crash".	The sound would be a good selection to clearly convey or suggest an immediate crash situation (i.e., this would be a good sound to use for the types of devices you saw in the video).
Urgency	The auditory warning conveys the proper sense of importance motivating an immediate response.	The sound conveys a sense of importance motivating you to make an immediate response.
Response Compatibility	The auditory warning causes the driver to anticipate and prepare for an emergency response.	NEW NAME: NATURAL RESPONSE The sound naturally causes the driver to anticipate and prepare for an emergency (i.e., without prior learning, this sound implies an impendiig emergency situation).
Experience Compatibility	The auditory warning follows natural or learned relationships of users, such as sirens associated with emergency, or words such as "DANGER" and "CAUTION" associated with warnings.	NEW NAME: EMERGENCY RELATIONSHIP The sound follows relationships users have learned to associate witb an emergency (i.e. the sounds or words used are usually associated with an emergency situation) .
Startle Effects	The auditory warning DOES NOT startle or surprise the driver causing a delayed reaction.	The sound produces startle.
Orienting Response	The auditory warning can be easily localized in 3-D sound space, and causes the driver to look in the diition of the hazard.	NOT TESTED IN MAE
Appropriateness	The auditory warning is compatible with the vehicle environment.	The sound is compatible with the vehicle environment (e.g. cars, trucks, etc.), i.e., the sound would not appear out of place if used as a warning in a car or truck.
Annoyance	The auditory warning IS NOT annoying or irritating to the driver (assuming minimal false alarm rates).	The sound is annoying.
Musciality	The auditory warning is melodious.	The sound is melodious and/or harmonious (i.e., the sound has musical qualities).
Naturalness	The auditory warning DOES NOT appear artificial or computer generated.	NOT TESTED IN MAE
Loudness	NOT ON QUESTIONNAIRE	The sound has high volume and intensity.

Questionnaire Analysis

The overall mean ratings and rankings for the attributes appear in Table 3.

TABLE 3: Questionnaire ratings and rankings

ATTRIBUTE	AVERAGE RATING (1-10)	ATTRIBUTE	AVERAGE RANKING (1-12)
Conspicuity	9.43	Conspicuity	2.97
Discriminability	9.23	Discriminability	3.15
Meaning	9.00	Meaning	3.50
Urgency	8.80	Urgency	4.26
Response Compatibility	8.63	Response Compatibility	5.65
Experience Compatibility	7.63	Startle Effects*	5.66
Startle Effects*	7.60	Orienting Response	6.49
Orienting Response	6.80	Experience Compatibility	6.53
Appropriateness	5.66	Appropriateness	7.81
Annoyance*	4.37	Annoyance*	8.43
Musicality	2.26	Naturalness	10.26
Naturalness	2.17	Musicality	10.74

* Indicates a negative attribute (see discussion below)

Although each attribute was rated and ranked on an absolute scale in terms of importance, some of these attributes are considered to be negative attributes. These negative attributes include Startle Effects and Annoyance. In these cases, a higher rating indicates a greater need to *minimize* the attribute.

The *razing* of the attributes was analyzed using a one-way within-subjects ANOVA of a single factor (attribute) having 12 levels. Thirty-five questionnaires were included in this analysis (one rating questionnaire was completed incorrectly). As expected, the main effect of attribute was significant ($p < 0.05$). A critical difference test between pairs of means was conducted to determine which attributes significantly differed in ratings.

The results of the critical difference test on the overall attribute ratings appears in Figure 2. In this figure, the top rated attribute earned the highest rating and is positioned at the top of the chart, followed by attributes in descending order of importance. The critical difference in mean ratings at a significance level of $p<0.05$ was calculated to be 0.82. As a result, the top five rated attributes do not significantly differ from one another based on this critical difference, and can be considered as all being equally important. Each member of this group is labelled with the letter "A". Consequently, the letters A-E indicate groups labels, where attributes with the same letter are not significantly different.

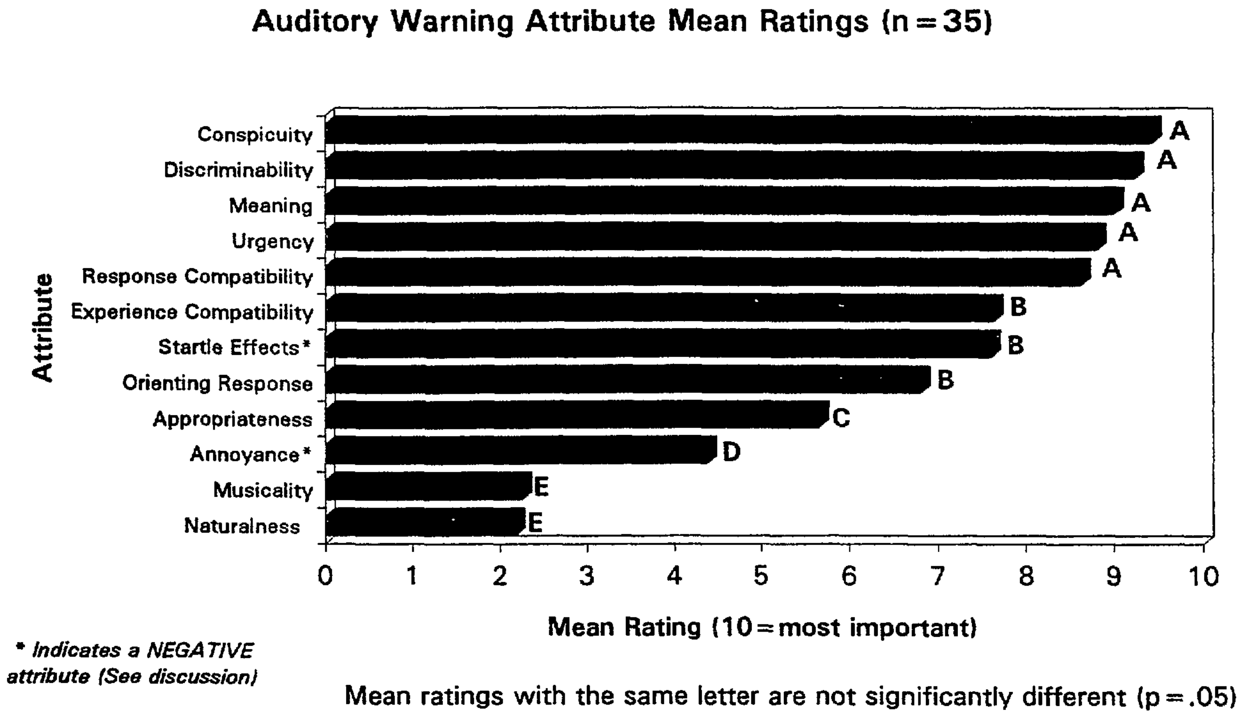
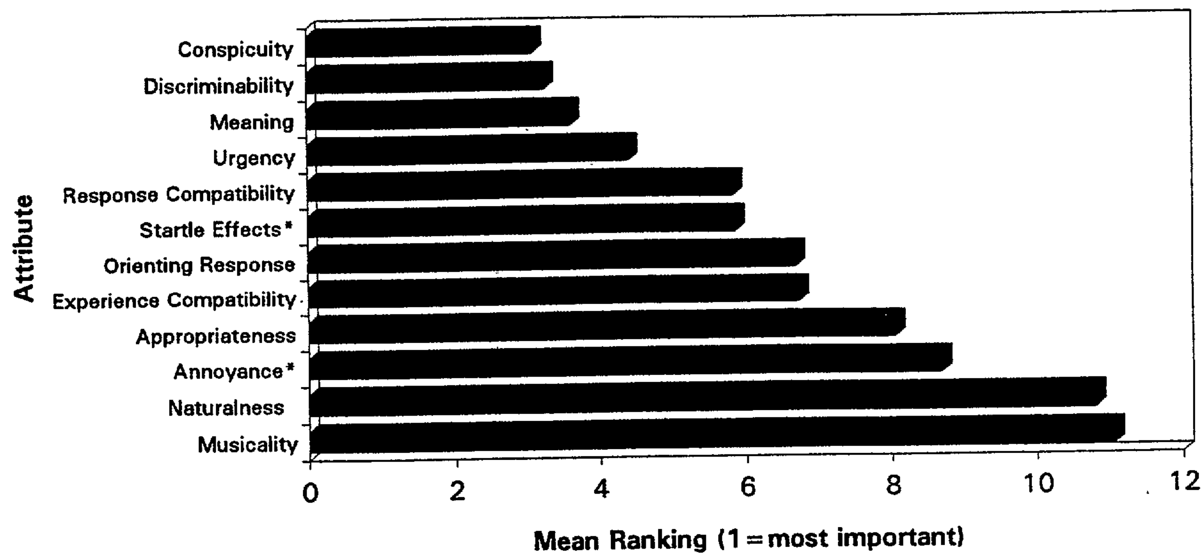


Figure 2: Attribute Rating Results

The results of the attribute rankings can be found in Figure 3. In general, attribute orders based on both ratings and rankings were highly correlated.

Auditory Warning Attribute Mean Rankings (n=33)



** Indicates a NEGATIVE attribute (See discussion)*

Figure 3: Attribute Ranking Results

Questionnaire Discussion

The questionnaire data provided information on the relative importance of each attribute in the development of an auditory warning signal. The top four attributes in both the rating and ranking tasks were 1) conspicuity, 2) discriminability, 3) meaning, and 4) urgency. Since, the ranking task was primarily included as a verification of the rating task, the rating data were used for the MAE evaluation, due to the high correlation in attribute order between these two tasks. Consequently, only the rating data are discussed below.

Five groups of attributes were rated significantly different from one another in the rating task. As shown in Figure 2, the top four attributes indicated above, along with Response Compatibility, scored equally well on the ratings. The top two attributes in the chart--Conspicuity and Discriminability--(based on mean rating) indicate that even a well designed auditory warning is ineffective, unless it is audible (#1 Conspicuity) within a background noise and unique (#2 Discriminable) from other ambient sounds. The remaining three attributes in this group are also among the more critical attributes associated with auditory warnings. Specifically, once attention is drawn to a unique sound, its meaning (#3 Meaning) must then be immediately recognized as being a warning. The perceived urgency (#4 Urgency) of the sound identified as a warning must then be conveyed in order to motivate a rapid response (#5 Response Compatibility).

The next group of attributes that were similarly rated includes Response Compatibility, Experience Compatibility, and Startle Effects. Although these three attributes were rated significantly less important than the first group, they do offer additional insight into a warning sound's performance. In particular, a warning sound's performance can be influenced by a person's past experience with other warning sounds. For instance, a siren is almost always associated with an emergency situation, while a warning that sounds like a fire alarm bell may be initially interpreted to be a warning of fire, regardless of its intention.

The rating of Startle Effects indicates that a warning should not cause a person to react in an inadvertent or delayed manner due to an initial startle response created by a sound. In particular, the sound should not be too loud or have too short an onset time, which can cause the sound to be perceived as being presented instantaneously. The last member of this group refers to the ability of the sound to instigate an orienting response towards its source. This attribute probably rates low due to its secondary information purpose.

The final three groups of attributes are relatively unimportant and possibly redundant in a warning signal's design. Specifically, the Appropriateness of a warning sound should be automatically achieved through attention to the Group A attributes, while Annoyance may refer not to a sound's effectiveness as a warning, but rather to the frequency at which a particular crash avoidance system might signal a false alarm. It is this false alarm frequency that can make an otherwise effective warning sound annoying. Finally, as discussed, the Group E attributes were included to encourage full use of the 10 point scale.

Based on the questionnaire results, the mean ratings for each attribute were used as the expert weightings in the MAE calculation matrix.

SELECTION AND DEVELOPMENT OF CANDIDATE WARNINGS

The set of 26 warning sounds used in the MAE evaluation was derived from a broad set of possibilities drawn from four different sources:

1) Existing auditory warnings and pre-recorded sounds
2) Off-the-shelf warning devices
3) New acoustic warnings developed to be compatible with recommendations in the COMSIS (1993) guidelines
4) Voice warnings developed to be compatible with recommendations in the COMSIS (1993) guidelines.

SOUND RECORDING AND GENERATION EQUIPMENT

The four‘categories of warnings were recorded or generated using a Sony DTC-700 Digital Audio Tape (DAT) deck, a 386DX/40 computer running a SoundBlaster 16 ASP SCSI-2 16-bit soundboard, a consumer grade microphone, and a CD player. The final recording medium for the warnings was the hard disk of the 386 computer using pulse-code-modulation (PCM) coded .wav files. The software used to record and edit the warning sounds was Turtle Beach Systems' Wave for Windows V2.04. Signal generation software was provided by Pioneer Hill Software's Spectra Plus Professional Version 3.0 software. Sources of warning sounds outside of the signal generation software included special effect sound libraries recorded from CD to DAT by recording studios, off-the-shelf electronic buzzers, live speakers, as well as voice synthesis functions provided by the SoundBlaster 16 ASP text-to-speech utility software TextAssist.

The range in presentation times for the warnings was due primarily to the completion of a particular warning's characteristic cycle. Warning sounds were not truncated to an equal length, but instead were presented in complete cycles. Short-duration sounds were repeated, however. For example, a particular acoustic warning repeated once may last 1.7 seconds, which was considered too short, but repeating the warning a third time may result in the warning being 2.4 seconds long (the desired range for acoustic warning length was chosen to be between 2 and 2.5 seconds). Voice warning presentation times, on the other hand, were based on a speech rate of approximately 156 words per minute (wpm) and only one repetition. As a consequence, voice warnings ranged in length from 1 to 1.4 seconds. Since, the top three warnings from each group were to be selected independent of sound type, the difference in presentation times between the acoustic and voice types was not a concern.

One-third octave band analyses and time-history plots are provided in Appendix B for all 26 acoustic and voice warnings. The one-third octave band analyses show the sound spectrum, or relative amount of acoustic energy in different frequency regions for each stimulus. If the energy is concentrated in the low frequencies (20-500 Hz), the sound will be perceived to have a low-pitch or rumbly sound. The two background noises (sedan and truck noise) are examples of such sound spectra (Figures 6 and 7). If the energy is concentrated in the mid-frequency region (500-2,000 Hz), the sound will be perceived to have a middle pitch. The speech stimuli (numbers 14-25) are examples of such sounds. If the energy is concentrated in the high frequencies (2,000-20,000 Hz), the sound will be perceived to have a high pitch, whiny or hissy sound. The Radio Shack Buzzer (Stimulus 5) is an example of such a sound.

The time-history or sound envelope plots in the lower panels portray the changes in sound level (amplitude) with time. If the sound is steady and continuous over the entire duration of the stimulus, the plot will show a steady band, like for Stimuli 6, 7 and 11-13. If the sound is intermittent or pulsed, the plot will exhibit bursts, like for Stimuli 3-5 and 8-10. The speech stimuli (numbers 14-25) have a characteristic rounded pulsed envelope representing syllables and words. An absolute scale was not attached to the time-history plots due to their variability in recorded sound level (presentation level was manipulated in real-time) and presentation length. For interpretation purposes, the y-axis on these plots is relative sound level (i.e., amplitude) while the x-axis is time. In addition, the time scale used to depict the waveforms was also relative, allowing the entire waveform of the presented stimulus to be viewed. In other words, each time-history plot contains the entire waveform for a stimulus lasting approximately 2-2.5 seconds for acoustic warnings (1.5 seconds for Stimulus 13: car horn) and 1 to 1.4 seconds for voice warnings (See "Voice warnings developed from guidelines" section). These plots were generated by the sound analysis software that was part of the sound generation equipment.

Three of the recoded stimulus waveforms (17, 18 and 20) experienced some clipping during post processing of the recorded sound. The occurrence is evident where the plotted amplitude (y-axis) appears flattened (Refer to Appendix B). This clipping was unnoticeable to the human listener.

WARNING CATEGORIES

Existing auditory warnings

Various manufacturers of crash avoidance systems on the market were contacted to attain information on the characteristics of the type of alarm used with their system. Although all of the manufacturers agreed that the type of warning is important, most of the manufacturers simply used an available alarm from electronic device suppliers. The only information attained on the characteristics of alarms used was that one alarm had a frequency of approximately 3400 Hz. Additionally, some alarms were said to increase in repetition rate or frequency as the potential hazard became more of a threat. Since these manufacturers did not conduct research on auditory warning appropriateness, samples of existing crash avoidance warning devices were not used for this study. Instead, two existing , highly critical alarms demanding immediate attention were selected from the flightdeck of an aircraft.

1) low-fuel aircraft warning (Stimulus 1)
2) take-off abort warning (Stimulus 2).

In addition to these existing warnings, two continuous complex tones were selected from the sound effects library. One was characterized a high frequency tone, while the other was considered a low frequency tone:

3) continuous tone high (Stimulus 6), approximately 5200 Hz
4) continuous tone low (Stimulus 7), approximately 1500 - 7000 Hz

Although emphasis was placed on evaluating specially developed sounds for warnings, the MAE also tested the existence of warning attributes in various vehicle environment sounds. These included the sound of a car horn and a recording of a tire skid. Therefore, two additional existing warning sounds included in the MAE were:

5) car horn (Stimulus 13)
6) tire skid (Stimulus 26).

Off-the-shelf warning devices
For practical applications, an off-the-shelf warning device would reduce design and fabrication costs. Therefore, several warning devices were purchased, and two of these were selected to be included in the study. The advantages of such devices include small size, low cost, and elimination of complicated and costly sound generation equipment. However, these devices do not provide voice warning capability. The part numbers of the devices selected for the study are as follows (one device operated in two modes):

1) Radio Shack #273-075 (Pulse Mode); (Stimulus 3)
2) Radio Shack #273-075 (Continuous Mode); (Stimulus 4)
3) Radio Shack #273-072 (Stimulus 5).

Acoustic warnings developed from guidelines
Generation of acoustic and voice warnings from scratch followed recommendations provided in the Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices (COMSIS, 1993). The guidelines included a short review of the current research and guidelines available for the development of auditory warnings. This section has been reproduced for this document and can be found in Appendix C. Section 2.4.5 of the guidelines begins the discussion of acoustic warning characteristics.

A total of five acoustic sounds were generated using a combination of signal generator and software editing tools. Three of the sounds were repetitive acoustic patterns that consisted primarily of four pulses which were presented at various intervals and relative amplitudes:

1) Pattern 1 (Stimulus 8)
2) Pattern 2 (Stimulus 9)

3) Pattern 3 (Stimulus 10).

The acoustic patterns were repeated at approximately 110 ms after the end of the pattern (approximately an 80 % duty cycle).

Two sweeping sine tones were also generated for the study with the following frequency sweeps and sweep times:

4) 1500-2000 Hz, 75 ms sweep time (Stimulus 11)
5) 2000-2500 Hz, 75 ms sweep time (Stimulus 12).

Voice warnings developed from guidelines

Section 2.4.6 of the guidelines (Refer to Appendix C) discusses the preferred characteristics of speech displays, and was the basis for the development of the candidate voice warnings. In addition to the characteristics specified in this section (i.e., 156 wpm, clearly mechanical, authoritative, etc.), the words "DANGER", "WARNING", and "HAZARD" were included in the voice warning characteristic combinations, as well as male and female digitized and synthesized voices. The voice warning words were presented at approximately 156 words per minute (WPM), and were repeated after about 125 ms. This speech rate was found to be the preferred rate for voice warnings in the literature, while the 125 ms pause between repetitions was near the minimum time required for a speaker to clearly and accurately repeat the word for recording. The difference between acoustic and voice warning lengths was due to the recommended speech rate and decision to repeat the voice warnings only once. The remaining twelve stimuli were the voice warnings as follows:

1) DANGER, male, digitized (Stimulus 14)
2) WARNING, male, digitized (Stimulus 15)
3) HAZARD, male, digitized (Stimulus 16)

4) DANGER, male, synthesized (Stimulus 17)
5) WARNING, male, synthesized (Stimulus 18)
6) HAZARD, male, synthesized (Stimulus 19)

7) DANGER, female, digitized (Stimulus 20)
8) WARNING, female, digitized (Stimulus 21)
9) HAZARD, female, digitized (Stimulus 22)
10) DANGER, female, synthesized (Stimulus 23)
11) WARNING, female, synthesized (Stimulus 24)
12) HAZARD, female, synthesized (Stimulus 25).

Loudness Attribute and Additional Stimuli

A total of twenty-six unique stimuli were created for the MAE experiment. In addition to these stimuli, however, two stimuli were created by manipulating the Sound Pressure Level (SPL) of Stimulus 5 (Radio Shack #273-072). These two stimuli were created by adjusting the SPL six decibels in both directions. The reason for adding these two stimuli is discussed in detail in the calibration and analysis sections. Although the stimuli were adjusted to be presented at the same loudness according to a sound level meter set on the A-weighting scale, there was a question about whether the perceived loudness of the warnings were indeed equal. Consequently, Loudness was added to the list of attributes to be rated, and a gross change in loudness was tested using a single sound to measure the effect of loudness on other attributes. The loudness attribute also served to measure perceived loudness equality relative to equal A-weighted decibel (dB(A)) readings across sounds. As a result, a total of twenty-eight warning sounds were created for use in the MAE experiment.

MULTIPLE ATTRIBUTE EVALUATION (MAE) EXPERIMENT

OVERVIEW OF DESIGN/PROCEDURE

Male and female participants in two age groups (20-40, and 65+) listened to all 28 warning stimuli, under two levels of simulated vehicle noise (sedan and truck) and rated each sound on 11 attributes, yielding a four factor, 2 x 28 x 2 x 11, mixed factorial design. The set of 28 stimuli was presented eleven times under each background condition, for rating on the basis of one of eleven different warning attributes. Each rating was made on a seven-point scale. The group mean ratings of each attribute comprise the primary data of the experiment.

PARTICIPANTS

Thirty-two (32) research participants consisting of two age groups, 16 subjects 65 years and over, and 16 subjects 20 to 40 years of age, were recruited for the experiment. Each participant participated in two sessions and was paid $20 for each session. All participants had valid drivers licenses. Participants were run in groups of 3-8 people, depending on the participant turnout and scheduling. There was an equal number of males and females from each age group.

APPARATUS

A block diagram of the apparatus is shown in Figure 4.

The major components of the apparatus included a Polk Monitor 611 satellite/sub-woofer system, two Infinity SM62 studio monitor speakers, a 386DX/40 IBM compatible computer controlling a Vetra VIP-412 RS-232 interface, a Radio Shack graphic equalizer, two Kenwood stereo amplifiers, a Radio Shack stereo mixer, a Panasonic TV monitor and Sony VCR, a Sony DAT deck, and eight participant response boxes. The 386 computer also controlled a SoundBlaster 16 ASP SCSI-2 16-bit sound board. The 16-Bit sound board is capable of recording and playing 16-bit stereo sound files of stimuli sampled at up to 44.1 kHz. In other words, frequencies up to 22 kHz can be sampled, stored, and played-back by this sound board.

The output of the sound board supplied signals to the Radio Shack mixer, which combined the background noise from the DAT with the stimuli signals from the sound board. The mixed signal was then fed to the Kenwood KA-791 and KRA-5060 amplifiers driving the Infinity and Polk speaker arrays, respectively. Stimulus sound level was software controlled and accomplished through adjustment of the sound output of the soundboard in 1 dB steps.

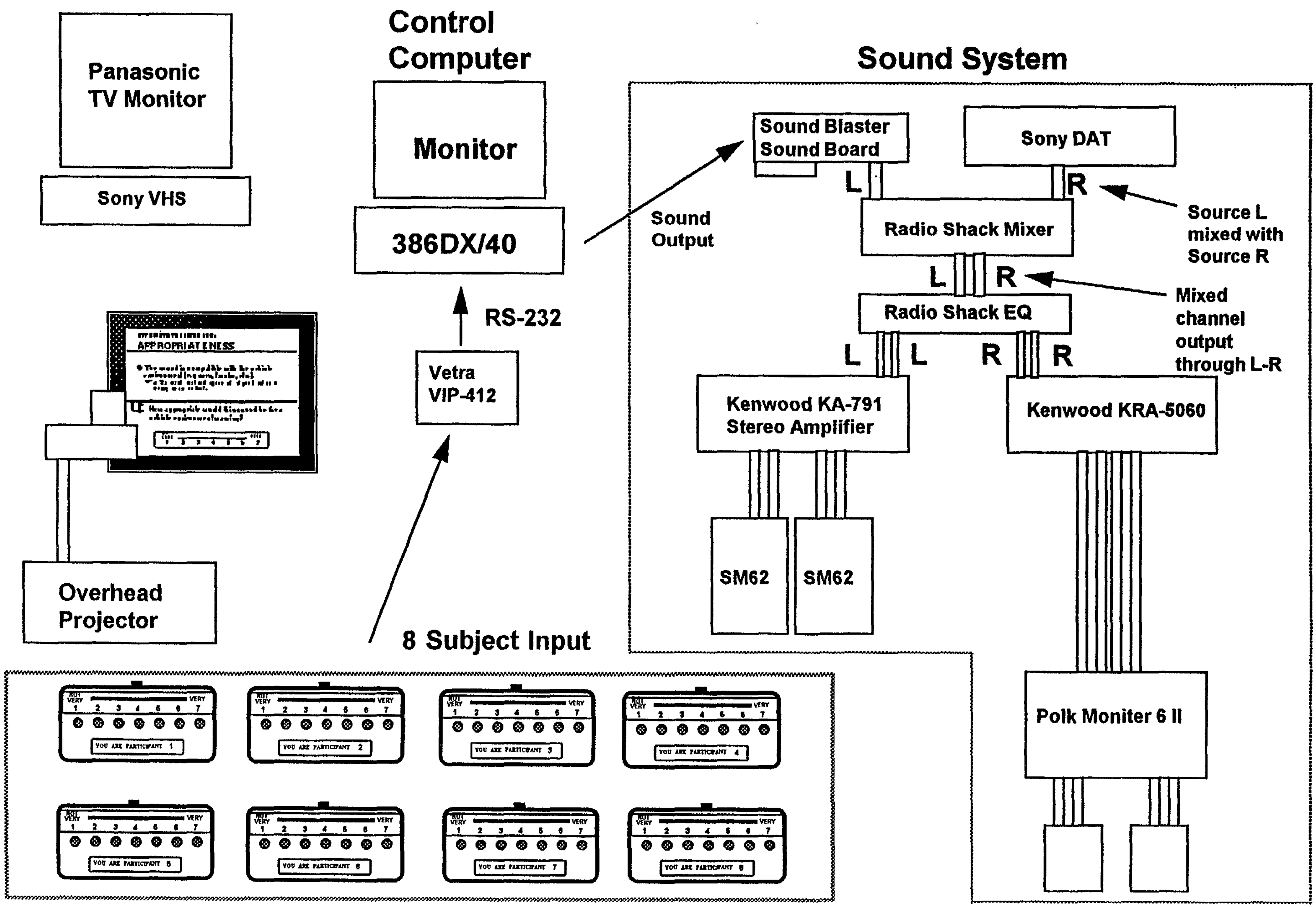


FIGURE 4: MAE Apparatus block diagram

The background noise level was adjusted using the mixer controls, while the levels between the Infinity and Polk speakers were equalized by adjusting the master volume controls on both amplifiers. A 386DX/40 personal computer was used to control data collection and stimulus presentation. A QBASIC program was coded that allowed data to be collect simultaneously from each of the 8 participant input devices. Each of the eight participant input boxes was connected to the Vetra VIP-412 RS-232 interface to allow the computer to register participant responses. Data collection was accomplished in real time by the computer.

A pink noise was used to calibrate the output of the sound card to ensure that all octave bands were equalized to within +/- 2 dB, with the exception of those centered below 125 Hz and above 8 kHz. These extreme bands do not comprise the predominant frequencies of the stimuli. The Radio Shack equalizer was used to equalize the frequency spectrum of each of the ambient noise speaker systems in each octave band using a pink noise, with the exception of those centered below 125 Hz and above 8 kHz Acoustical calibration of the equipment is discussed in the following section.

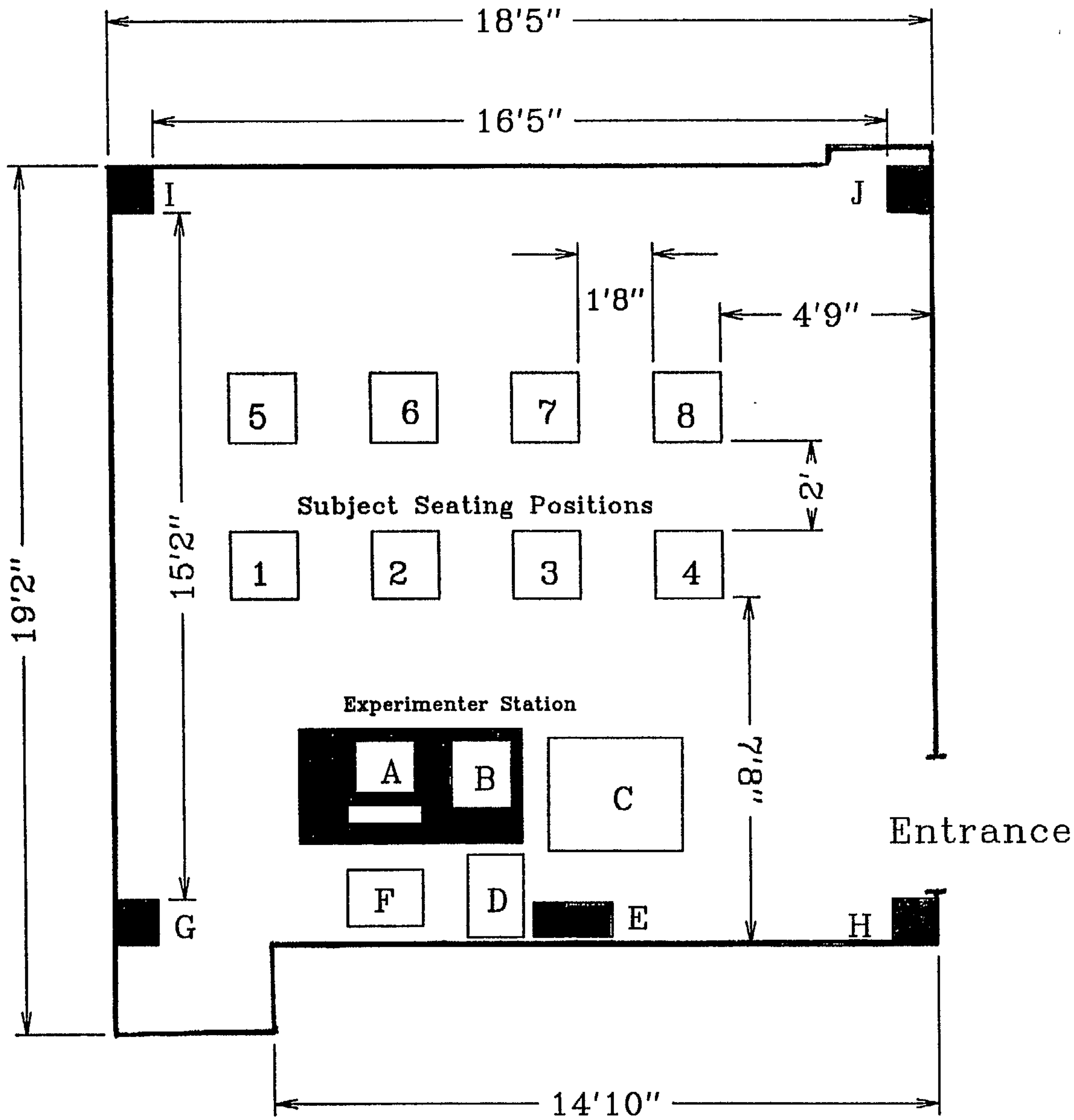
ENVIRONMENT

A layout of the laboratory environment is shown in Figure 5.

Participants were seated in two rows of four folding metal chairs each. Depending on the. scheduling and attendance, the number of actual participants tested at one time was between 3 and 8 participants. For test groups less than 8 participants, the participants filled chair positions in order of seat numbers. The experimenter was seated facing the participant and controlled the computer, overhead projector, and sound generation equipment. The four speakers were situated in the comers of the room (virtual comers in two cases) and were angled toward the center of the room. Each speaker was situated on a speaker stand to be at ear level of a seated subject. The subwoofer for the Polk Monitor 6II system was situated along the center of the front wall. The TV cart was used only during the instructional phase of the study.

Background noise characteristics

The two noise environments selected were from a passenger vehicle and a heavy truck cab. For this study a sedan noise and a truck noise attained from a CD special effects library were utilized. The background noise of the passenger vehicle was recorded in a late model compact vehicle, while interior truck noise was attained inside the cab of a heavy truck. The recordings were made at highway speeds with the windows-up and radio communications off. The special effects library used was developed by Sound Designs. One-third octave band analyses of these two sounds arc shown in Figures 6 and 7. These sounds were presented at 72 dB(A) and 78 dB(A) respectively (measured in the center of the room).



LEGEND:

1 - Subject 1
2 - Subject 2
3 - Subject 3
4 - Subject 4
5 - Subject 5
6 - Subject 6
7 - Subject 7
8 - Subject 8

A - Control CPU
B - Overhead Projector
C - TV Cart
D - Amplifiers, Mixer, Equalizer, DAT
E - Polk Monitor 6II Subwoofer
F - Experimenter Chair
G - Polk Monitor 6II Satellite
H - Polk Monitor 6II Satellite
I - Infinity SM-62
J - Infinity SM-62

FIGURE 5: Laboratory layout of the MAE experiment

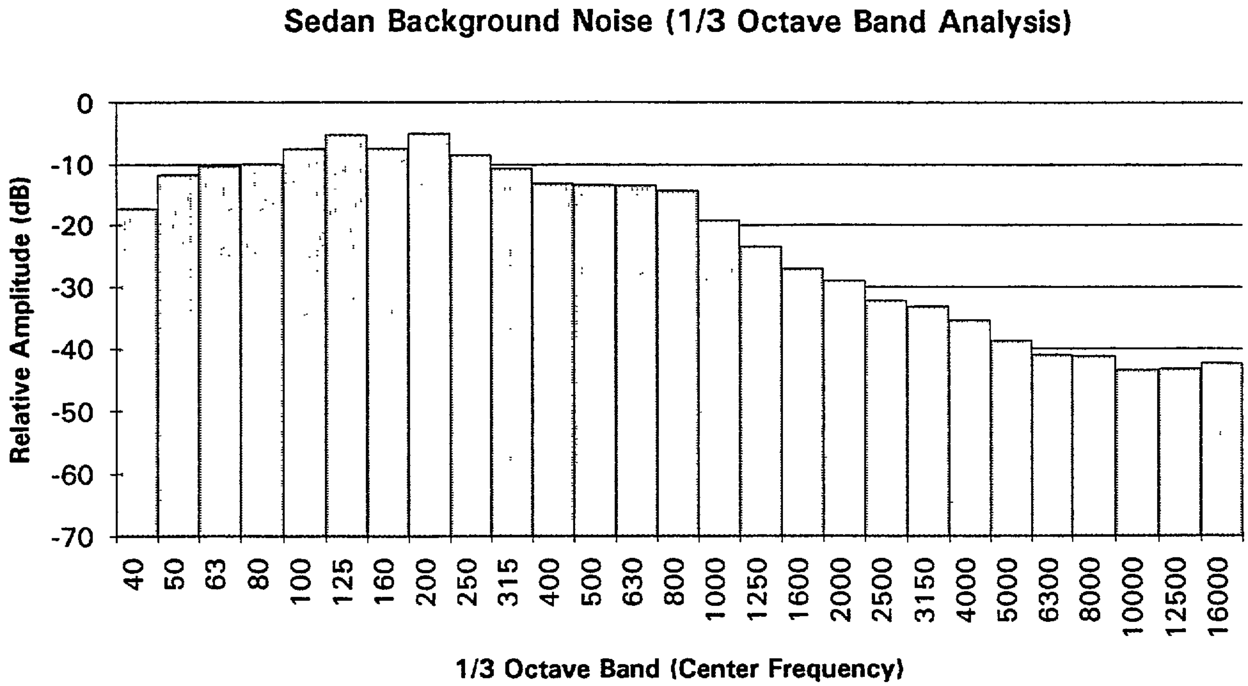


FIGURE 6: Sedan background noise (1/3 octave band analysis)

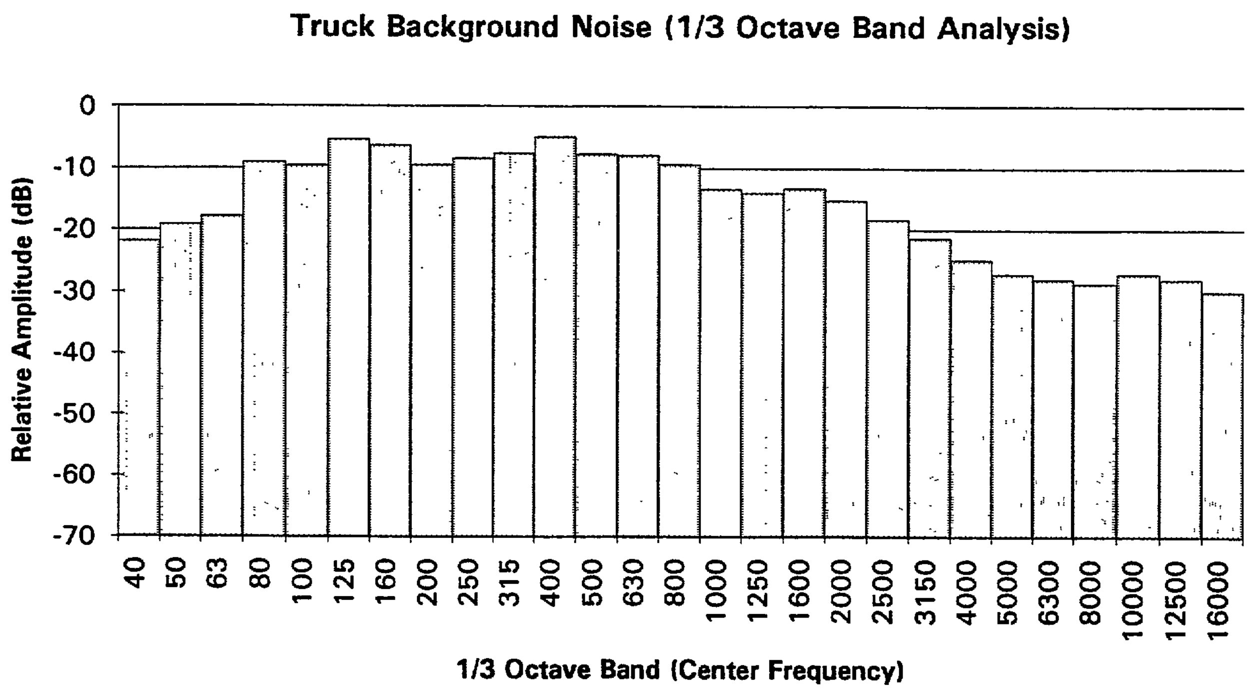


FIGURE 7: Truck background noise (1/3 octave band analysis)

Acoustical Calibrations

Frequency equalization was conducted using a pink noise source for the four-speaker audio system. A +/- 3 difference in frequency response at each octave band was achieved across each of the eight participant positions. The octave bands centered at 31.5 and 16,000 Hz were ignored from this calibration, since these octave bands were both difficult to equalize and largely irrelevant to the stimuli and background noise presentation. The equalization curves achieved at each of the eight seating positions are shown in Table 4. In addition to this equalization, the output of the sound board was also equalized to achieve similar performance.

The stimuli were calibrated for presentation (in absence of background noise) at similar A-weighted sound levels. Due the complex dynamic characteristics of many of the sounds, they were not easily measured with a sound level meter. Consequently, subjective perceptual responses (e.g., loudness, intrusiveness) may be imperfectly related to measured values. Nonetheless, equalizing on the basis of measured sound intensity tends to bring all of the stimuli to relatively similar perceived intensity levels. The calibration was accomplished by using the sound level meter and adjusting the output level of the sound card for each sound until the sounds were all at the same A-weighting sound level (i.e., equal dB(A) reading). Once this level was achieved for each sound, the setting of the soundcard was recorded and the respective settings were used each time a particular stimulus was presented. This calibration was performed outside of the background noise in order to eliminate possible contamination of the measurement by the background noise. By approximating equal loudness outside of the background noise, the robustness of each stimulus can be assessed between quiet conditions and near worse case noise masking scenarios. This calibration procedure is discussed further in the MAE conclusions section.

Octave Band Center Freq.	Center of Room dB(C)	Seating Position dB(C) 1	2	3	4	5	6	7	8	High-Low dB(C) in Octave Band
31.5	67	74.4	75.8	75.3	75.3	67.5	66.6	67.5	67.7	n/a
63	72	72.9	74.1	70.0	70.6	73.0	70.6	**68.8**	**75.0**	6.2
125	76	**76.4**	74.6	74.2	74.6	72.8	74.7	**70.3**	72.7	6.1
250	75	73.8	**71.8**	74.3	75.0	73.1	**75.6**	74.5	73.6	3.8
500	74	73.5	73.8	74.3	74.3	**73.1**	74.9	74.0	**75.5**	2.4
1,000	74	73.5	75.2	**76.2**	75.3	73.8	76.0	76.0	**73.4**	2.8
2,000	76	**72.8**	74.0	74.4	73.1	73.4	73.8	**74.7**	72.8	1.9
4,000	76	76.3	75.9	76.6	**75.7**	76.1	75.9	**77.2**	75.9	1.5
8,000	74	74.6	73.9	74.8	**73.1**	**75.2**	74.4	74.4	73.9	2.1
16,000	68	66.8	67.5	66.9	65.0	68.3	67.8	68.7	66.2	n/a
								Average		3.4
								Maximum		6.2

TABLE 4: Acoustical calibration of laboratory environment

Input Device

The input device used by each participant consisted of 6” (l) X 3” (w) X 2” (h) box with seven buttons. A label indicating the direction of the scale and corresponding button for each point on the scale was also provided. A label indicating to the participant his or her participant number was also included to aid participant prompting during the experiment. An illustration of the input box is shown in Figure 8.

EXPERIMENTAL STIMULI

As discussed in the Selection and Development of Candidate Warnings section, there were a total of twenty-eight candidate warnings tested. All stimuli (except 27 and 28) were presented at **6** dB (A) above the background noise level. These levels were 78 dB(A) and 84 dB(A) for sedan and truck background conditions respectively. Stimuli 27 and 28 were presented at + 6 dB and - 6 dB respectively, relative to the loudness equalized Stimulus 5.

EXPERIMENTAL DESIGN

The experiment was a 11 x 28 x 2 x 2 mixed factorial design with sixteen participants in each cell. Each participant underwent 616 unique conditions. The factors of the experiment were attribute (11 levels), auditory warning stimulus (28 levels), background noise (2 levels), and age (2 levels). As a result of the number of experimental conditions, data collection was accomplished in two sessions (blocked by background noise) within a one week period. Age was nested within participants yielding sixteen participants in each cell.

Independent variables

The following independent variables were manipulated:

Attribute (11 levels)

Although there were twelve attributes included in the questionnaire mailing, some of those attributes were not tested in the MAE, while others were added. In particular, Orienting Response was not tested in the MAE since it would be difficult for a participant to voluntarily rate the likelihood that the sound would instigate an orienting response. Furthermore, Naturalness was not tested in the MAE, due to its insignificance as a desirable warning attribute. While these two attributes were removed, Loudness was added to the list to bring the total number of attributes tested to 11.

Auditory warning stimuli (28 levels)

As described in the Selection and Development of Candidate Warnings and Experimental Stimuli sections.

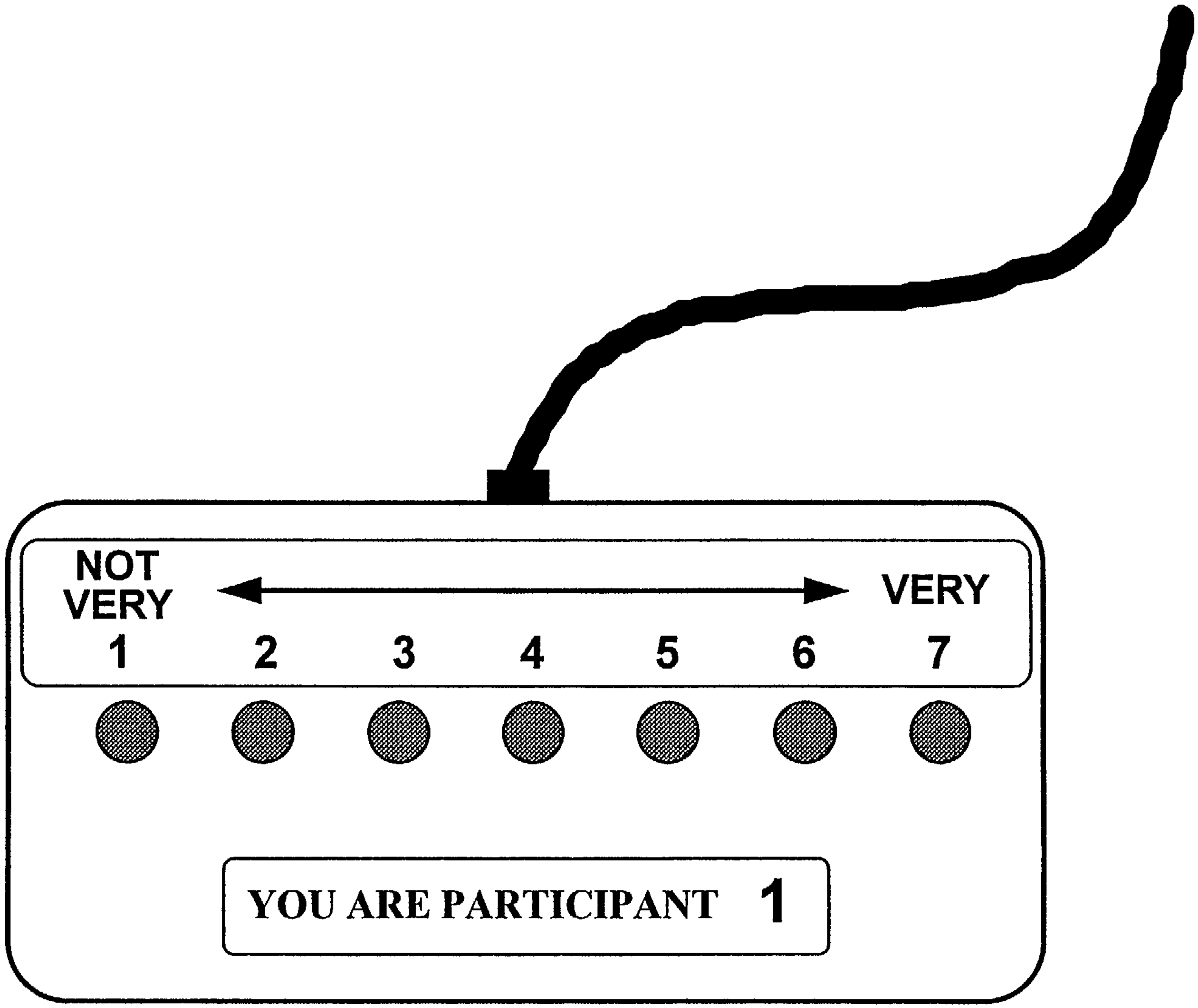


FIGURE 8: Seven button input device for MAE attribute rating

Background noise (2 levels)
As described in the Environment section of the MAE Experiment, a sedan and heavy truck interior noise was presented as background noise.

Age (2 levels)
The two age groups that were investigated in this study included participants aged 20 to 40 years and participants aged 65 years and over. An equal proportion of male and female participants from both age groups were tested.

Presentation Order
Experimental sessions were blocked on background noise, while experimental trials within sessions were blocked on attribute. Attribute order was completely randomized within each session and the presentation order of the 28 stimuli was completely randomized within attribute. The Musicality attribute was always tested during the practice session.

The timing of the stimulus presentations was both participant- and computer-paced That is, if all participants within a test group did not enter a response within 5 seconds after a stimulus finished playing, the experimenter instructed the appropriate subject(s) to make a response. On the other hand, if all participants entered a response before 5 seconds, the computer would automatically begin preparation for the next stimulus. Each stimulus was presented for approximately 2 to 2.5 seconds for acoustic and 1 to 1.5 seconds for voice warnings. In addition, the computer randomly selected a time within a specified presentation time window to play the warning sound. The window for this study was 7 seconds long (one second increments) and each duration had an equal probability of occurring. This presentation window was used to prevent the participant from learning a pattern of stimulus presentation time and, therefore, not accurately rating the sounds on such attributes as Startle Effects. This presentation window began after a fixed time of approximately 4 seconds after the last participant response was registered. Consequently, the time between the last participant response and the next stimulus was between 5 and 11 seconds.

Dependent Variables
The dependent variable measured in this experiment was a rating from 1 to 7 on the magnitude of a particular attribute for a given sound. Although 11 different attributes were included in the design, the ratings for each attribute within each sound were weighted and summed to achieve a total weighted score for use as the dependent variable in the analysis. Discussion of the analysis procedures appears in the MAE Analysis section.

PROCEDURES

Participant Screening and Consent
Participants were contacted by phone or through flier circulation and were screened for age, gender, and driving status (each participant held a current driver's license) in order to fulfill the experimental design requirements. A copy of the demographic information form used

during the screening procedure appears in Appendix D.

Informed Consent

Participants allowed to take part in the study were required to complete an informed consent form once they arrived for the experiment. A copy of this form appears in Appendix E.

Training

This portion of the procedure consisted of an instructional phase where the experimenter described the necessary tasks the participants were required to perform during the experiment. This was accomplished in verbal form, where the experimenter reviewed the instructions with the participants (the verbal instructions given to the participants can be found in Appendix F). During the training, the participants were first shown a five minute Department of Transportation video entitled, "Avoiding crashes - New solutions from multifaceted research" to provide an introduction to the type of vehicle systems where the sounds might be employed. In addition, the participants were familiarized with the input devices and attribute rating procedure.

Practice Session

Once all participants were comfortable with the procedure, a practice session was conducted which required the participants to rate all of the twenty-eight stimuli on the attribute of Musicality. This practice session familiarized the participants with the experimental procedure and also with the range of sounds they would be rating. The experimental procedure is described below.

Experimental Trials

Once the practice session was completed, the participants began the actual data collection by performing the ratings of the stimuli on each of the attributes. The data collection procedure involved the experimenter first describing the attribute to be rated by presenting its definition on the overhead projector (see Appendix G for attribute definition overheads). Once participants were comfortable with the definition, the twenty eight sounds were presented as described. The current attribute being rated remained on the overhead projector until all sounds were rated on that attribute. Participants were allowed to ask questions during description of the attribute definition, but were not allowed to ask questions during the test. With the exception of the experimenter prompting for unregistered inputs (due primarily to buttons not being pressed fully), the experiment ran automatically during each attribute test. Two breaks were given during the experiment--one at the end of the fourth and seventh attribute. Each of the two sessions (sedan and truck conditions) was approximately 1 hour and 30 minutes in length.

MAE ANALYSIS

The analysis of the MAE data consisted of the following components:

(1) Analysis of Variance to determine significant effects
(2) Application of the attribute weighting to define the MAE matrix and weighted scores for each stimulus
(3) Descriptive statistics for each rated attribute under each background noise condition and their intercorrelations
(4) Treatment of perceived loudness confounds through the use of linear regression analysis.

Based on these analyses, a set of candidate warning sounds was selected for consideration in subsequent research.

ANALYSIS OF VARIANCE

The effect of sound stimulus on the total weighted score was evaluated in separate Analysis of variance (ANOVA) procedures for the set of acoustic stimuli and the set of voice stimuli. A two-factor analysis was done to evaluate the influence of the warning stimulus, the background noise, and their interaction. A second set of ANOVA procedures was also conducted to assess the influence of warning stimulus, age group, and their interaction on the total weighted score.

Analyses of the difference in ratings between background noise and sound type were conducted using separate 2-way repeated measures ANOVA procedures (i.e., two designs (n =32) each having 2 levels of background noise x 16 levels of sound type for acoustic warnings, and 2 levels of background noise x 12 levels of sound type for voice warnings respectively).

For acoustic warnings, the analysis of the ratings of the sounds in the two background noises indicated a main effect for sound and background and no interaction at the significance level of $p<0.05$ Overall, the participants rated the acoustic warnings higher in the truck background noise. For the voice warnings, only a main effect for sound type was identified. Since no interaction between sound and background was identified, the sedan background noise was chosen for use in the selection of optimal warning sounds using the MAE calculations, bar charts, and scatter plots discussed in the following sections.

To analyze the differences in ratings between age (20-40 and 65 and over) and sound, separate 2-way mixed factorial Analysis of Variance procedures were performed on the total weighted score for acoustic warnings and voice warnings (i.e., two designs (n = 16) each having 2 levels of age x 16 levels of sound type for acoustic warnings, and 2 levels of age x 12 levels of sound type for voice warnings respectively).

The results for the age and acoustic sound analysis indicated a main effect for age and sound as well as an interaction between age and sound. In general, older participants provided higher ratings than the younger age group, however, the magnitude of this difference varied among sounds. Four sounds that were rated significantly lower overall by the older age participants were Stimulus 1, 6, 9, and 26. Based on the octave band analyses for these sounds (refer to Appendix B), the lower ratings for these sounds may indicate the existence of presbycusis (age induced hearing loss), since these sounds have a high proportion of sound energy in the frequency band prone to presbycusis onset. The results for the age and voice sounds indicated only a main effect for sound type.

MAE MATRIX CALCULATION

The attribute ratings made by each participant for each of the twenty-eight warning signals were averaged across participants and entered appropriately into the MAE matrix in order to calculate the composite weighted scores. Each of the average attribute ratings for each sound were then weighted using the average expert rating on each attribute attained from the questionnaire. The weighted attribute ratings were then summed to achieve a total weighted score for each warning. A separate MAE matrix calculation was made for both sedan (See Table 5) and truck background noise (See Appendix H) conditions. As concluded from the ANOVA procedures, since the background noise and sound type interaction was not significant, interpretation of the MAE calculation, bar charts, and scatter plots was based on the results attained in the sedan background condition.

As mentioned earlier, startle effects and annoyance attributes were negatively weighted in this MAE calculation. This was necessary to account for the fact that the definitions were worded in a negative fashion (i.e., to what extent must these attributes be minimized). Table 6 shows the total weighted scores for both the acoustic and voice warning sounds in both the sedan and truck background noises. This figure is simply the sedan results from Table 6 and truck results from Appendix H in tabular form. The sounds are ordered from highest to lowest total score.

As anticipated, Stimulus 27, which was presented at 6 dB higher than the nominal value for other stimuli, had a higher MAE total-weighted score than other acoustic stimuli. Likewise, Stimulus 26, which was presented 6 dB lower than the nominal value of other stimuli, had the lowest MAE total-weighted score among acoustic stimuli. This suggests a dominant role of loudness, which will be addressed below. The voice stimuli generally scored lower than the acoustic stimuli.

As shown in Table 6, the MAE calculation for sedan background noise found that the top acoustic stimuli (not including Stimulus 27 and 28) in order of highest to lowest score were 1, 8, 10, and 5, and the top voice stimuli were 14, 20, 15, and 16 [Similarly, the truck

ATTRIBUTE	ANNO	APPR	DISC	EMER	LOUD	MEAN	MUSI	NRES	NOTI	STAR	URG	WEIGHTED SCORES
EXPER RATING	-4.37	5.66	9,.23	7.63	0	9	2.26	8.63	9.43	-7.6	8.8	
ALTERNATIVE												
1	6.28	5.72	6.63	6.50	6.41	5.94	2.72	6.59	6.59	5.63	6.22	299.45
2	4.44	5.06	4.44	4.38	4.91	4.22	3.31	4.56	5.06	4.75	4.53	219.93
3	4.69	4.66	4.97	4.53	5.00	4.19	3.03	4.78	5.25	4.88	4.50	224.15
4	3.97	4.69	5.09	4.47	4.50	3.97	4.69	4.63	5.31	4.66	4.09	227.22
5	5.38	5.81	5.94	6.06	6.13	5.25	4.25	5.69	6.22	5.97	5.53	278.34
6	5.16	4.47	4.75	4.50	5.25	4.19	3.06	4.53	4.69	4.66	4.53	213.32
7	5.59	4.81	5.31	5.13	5.75	4.53	2.59	5.03	5.69	5.63	4.69	233.12
8	5.28	5.59	6.34	5.94	6.13	5.47	4.22	6.13	6.22	6.13	6.09	289.73
9	4.38	4.63	5.19	4.91	4.91	4.25	3.47	4.81	5.09	4.78	4.56	231.83
10	5.28	5.63	6.25	5.88	6.19	5.66	3.75	6.13	6.13	6.03	5.86	287.03
11	4.16	4.47	5.00	4.47	4.75	3.75	4.56	4.31	53.19	4.91	3.94	214.93
12	5.00	4.56	5.56	4.88	5.13	4.19	4.41	4.63	5.28	5.22	4.81	232.59
13	5.28	4.88	4.63	4.91	5.50	4.22	3.34	4.94	5.16	5.53	4.88	222.48
14	3.56	4.69	4.50	4.59	5.00	4.38	3.31	4.88	4.97	4.13	4.69	233.31
15	3.59	4.28	4.50	4.34	4.28	4.06	3.31	4.44	4.81	3.84	4.41	220.51
16	3.25	4.50	4.34	4.16	4.22	3.97	3.41	4.50	4.53	3.72	4.19	216.66
17	3.09	3.91	4.22	3.91	3.44	3.56	2.94	4.25	4.25	3.22	3.94	203.05
18	2.53	3.34	3.16	3.09	2.53	2.59	2.44	3.31	3.25	2.44	2.91	155.69
19	2.63	3.06	3.00	2.88	2.66	2.25	2.66	3.16	3.16	2.41	2.81	145.23
20	3.59	4.44	4.56	4.19	4.25	4.19	3.47	4.31	4.63	3.81	4.50	220.55
21	3.13	3.69	3.97	3.81	3.41	3.31	3.22	4.03	4.00	3.38	4.16	193.41
22	3.09	3.59	3.56	3.09	2.63	3.09	2.78	3.28	3.69	2.41	3.19	170.20
23	3.03	3.28	2.94	2.50	2.22	2.50	2.44	2.84	3.09	2.34	2.81	140.14
24	2.56	2.88	2.72	2.41	1.84	2.09	2.50	2.78	2.84	2.25	2.41	127.95
25	3.31	3.38	3.31	2.94	2.81	2.78	2.50	3.41	3.31	2.78	2.94	153.71
26	5.03	3.38	3.84	3.41	4.03	4.03	1.66	4.16	4.47	4.25	3.81	177.91
27	5.97	5.97	6.56	6.66	6.72	6.16	3.69	6.44	6.53	6.44	6.50	308.26
28	3.88	4.63	4.69	4.81	3.81	3.81	4.72	4.59	4.91	4.28	4.16	224.19

Table 5: MAE matrix calculation for sedan background noise condition

SEDAN

ACOUSTIC STIMULI	MAE SCORE	VOICE STIMULI	MAE SCORE
27	308.26	14	233.31
1	299.45	20	220.55
8	289.73	15	220.51
10	287.03	16	216.66
5	278.34	17	203.05
7	233.12	21	193.41
12	232.59	22	170.20
9	231 .83	18	155.69
4	227.22	25	153.71
28	224.19	19	145.23
3	224.15	23	140.14
13	222.48	24	127.95
2	219.93		
11	214.93		
6	213.32		
26	177.91		

TRUCK

ACOUSTIC STIMULI	MAE SCORE	VOICE STIMULI	
27	318.26	14	224.56
1	309.47	15	224.08
5	291 .08	16	206.91
10	281.06	17	206.02
8	266.58	20	195.17
4	256.67	21	90.82
13	256.16	25	177.12
2	248.41	23	170.65
9	244.04	22	163.01
7	240.51	18	157.43
12	239.61	24	149.25
11	234.74	19	139.53
3	230.81		
28	223.90		
6	219.35		
26	203.50		

Table 6: Total scores for sounds in sedan and truck and background

background condition yielded the top acoustic warnings to be 1, 5, 10, and 8 for acoustic and 15, 16, and 17 for voice]. Since the MAE calculation produces a total weighted score, performance on individual attributes was also assessed in order to ensure that these top stimuli performed well on the most important attributes, and that existence of poor attributes was minimal. The remaining analyses, discussed below, were conducted to account for individual attribute performance.

INDIVIDUAL ATTRIBUTE RATINGS

Bar charts were created to illustrate attribute rating and total weighted score as a function of warning sound. A total of twelve charts are included in this document (11 attribute vs sound and 1 total score vs. sound). The bar chart shown in Figure 9 depicts the total weighted score for each of the 28 warning sounds in both sedan and truck background noises. For consistency, the numbers 1 to 28 on the x-axis correspond to the stimulus numbers used earlier in this document. For convenience, the description of each of the 28 sounds is repeated below:

1) low-fuel warning (Stimulus 1)
   - rapid wailing siren
2) take-off abort warning (Stimulus 2)
   - slow, pulsed, whistle-like tone
3) Radio Shack (Pulse Mode) (Stimulus 3)
   - approximately 3500 Hz peak pulsed beep
4) Radio Shack #273-075 (Continuous Mode) (Stimulus 4)
   - high-pitched ambulance-like siren
5) Radio Shack #273-072 (Stimulus 5)
   - low-pitched ambulance-like siren
6) continuous tone high (Stimulus 6)
   - narrow spectrum with peak centered at approximately 5200 Hz
7) continuous tone low (Stimulus 7)
   - broader spectrum than stimulus 6 with more low frequency energy
8) Pattern 1 (Stimulus 8)
   - 2500 & 7500 Hz broad pulse of 110 ms each repeated at 8 ms intervals, pause of 110 ms
9) Pattern 2 (Stimulus 9)
   - 5200 Hz, two paired bursts with a longer pause between a repeated set of paired bursts
10) Pattern 3 (Stimulus 10)
    - narrow 2600 & 7800 peaks, temporally similar to Pattern 1
11) 1500-2000 Hz, 75ms sweep time (Stimulus 11)
12) 2000-2500 Hz, 75ms sweep time (Stimulus 12)
13) car horn (Stimulus 13)
14) DANGER, male, digitized (Stimulus 14)
15) WARNING, male, digitized (Stimulus 15)
16) HAZARD, male, digitized (Stimulus 16)

17) DANGER, male, synthesized (Stimulus 17)
18) WARNING, male, synthesized (Stimulus 18)
19) HAZARD, male, synthesized (Stimulus 19)
20) DANGER, female, digitized (Stimulus 20)
21) WARNING, female, digitized (Stimulus 21)
22) HAZARD, female, digitized (Stimulus 22)
23) DANGER, female, synthesized (Stimulus 23)
24) WARNING, female, synthesized (Stimulus 24)
25) HAZARD, female, synthesized (Stimulus 25)
26) tire skid (Stimulus 26)
27) Stimulus 5 (+6 dB)
28) Stimulus 5 (-6 dB)

Figure 10 illustrates the relatively small effect of background noise on total weighted score. In addition, the significant effect of sound type (acoustic or voice) is visible. For voice warnings digitized speech (i.e., 14, 15, 16, 20, 21 and 22) appears to be more effective than synthesized speech (i.e., 17, 18, 19, 23, 24 and 25).

A final point to note on Table 5 is the performance of Stimulus 27 and Stimulus 28. As described earlier, Stimuli 27 and 28 were simply Stimulus 5 presented at different sound levels (+/- 6 dB) As is readily apparent, loudness heavily influences total weighted score. The 12 dB span of intensity for this sound resulted in a change in the total MAE score of about 130 units, or 10.8 units per 1 dB increase in sound level. Thus the rated "goodness" of a warning sound is strongly related to its perceived loudness. Figure 10 shows the loudness attribute ratings for each stimulus. Despite the approximate equalization of stimuli in terms of A-weighted sound level, there remained noticeable differences in the perceived loudness to subjects. Note that the difference in rated loudness between Stimulus 27 and Stimulus 28 is about 3 rating scale units. There is a comparable range of loudness ratings among the other stimuli in the set. This suggests that despite the initial equalization based on the dB(A), the perceptual difference in the loudness of the various sounds may have been the result of stimuli differing in equivalent presentation on the order of 12 dB or more. Equating sounds for A-weighted sound level represents only a first-approximation to actually equating the sounds for equal loudness. Better loudness estimation schemes exist, but even these are still approximations. The only accurate way to equate sounds for loudness, which is an entirely subjective quantity, is to perform psychophysical loudness judgement experiments. The human ear is exquisitely sensitive to sound frequency sound level, frequency modulations, level modulations, rise-time, fall-times, temporal envelope, etc. These all contribute in subtle ways to loudness judgements so that no simple weighted sound level measurement can possibly serve to capture all of these important influences. The implications of this for interpreting the findings are discussed below.

The remaining bar charts, illustrating the rating of the 11 attributes on each of the 28 sounds, can be found in Appendix I.

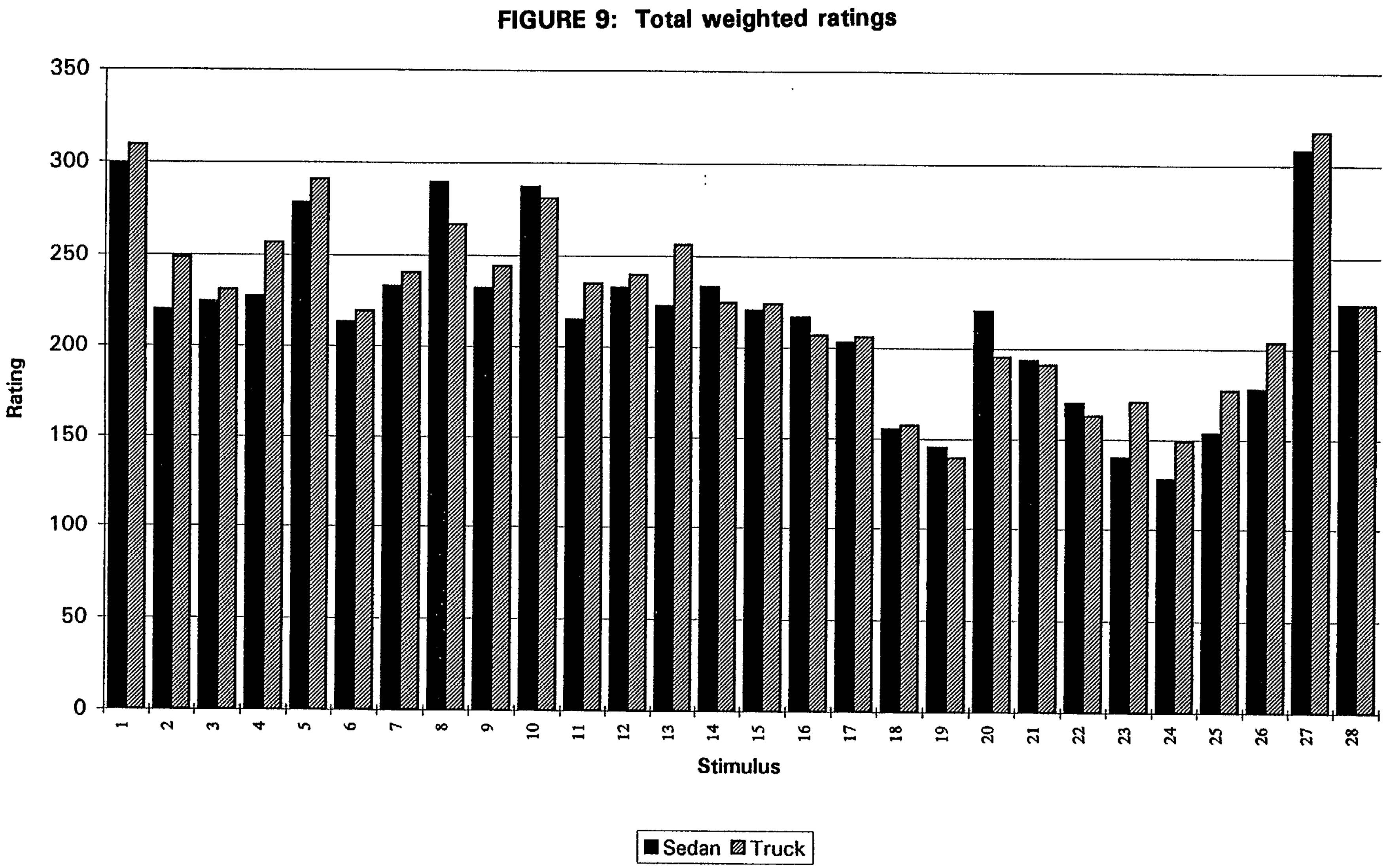


FIGURE 9: Bar chart of total weighted score for each in both background noises

FIGURE 10: Bar chart of loudness ratings for each sound in both background noises

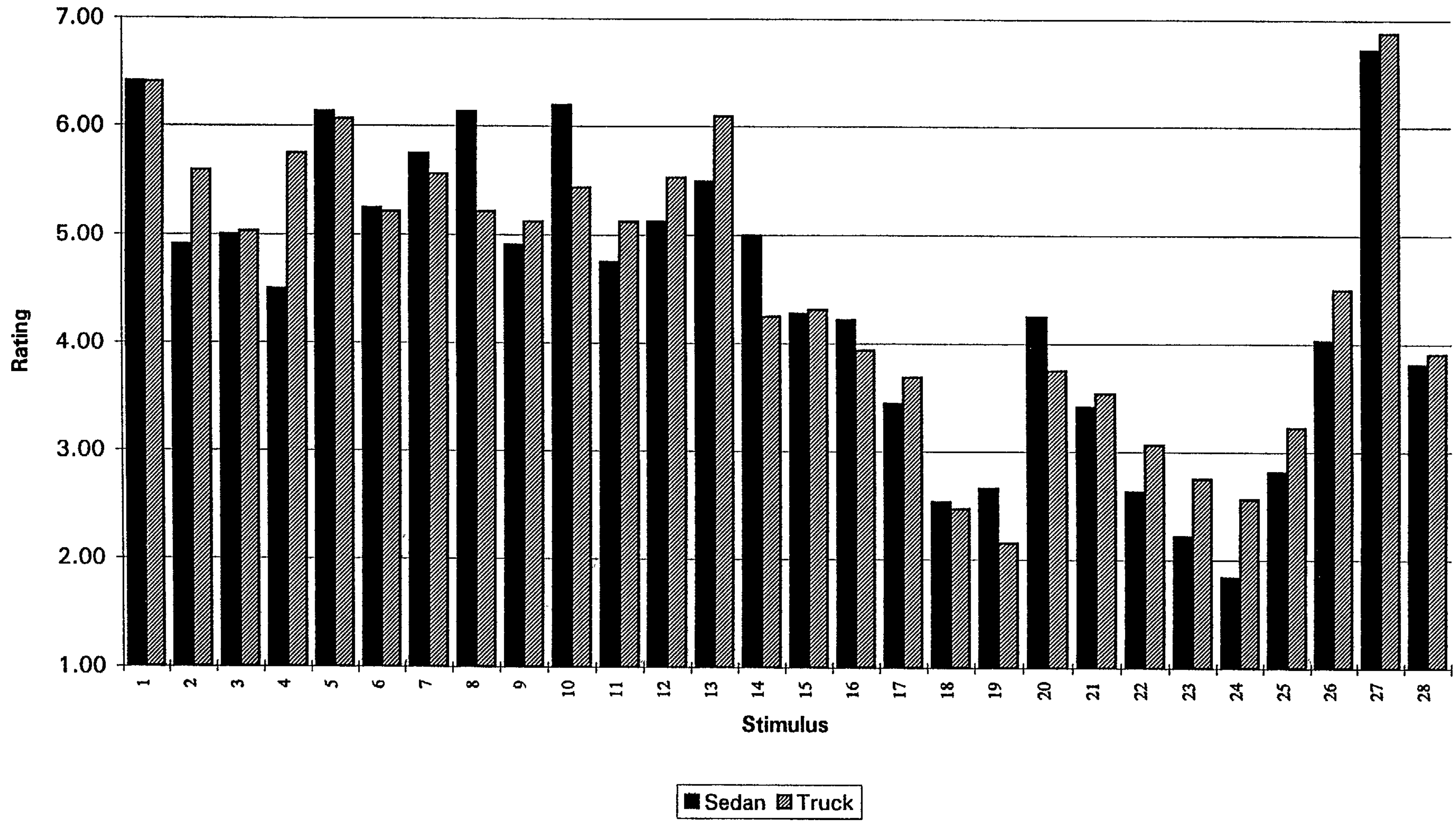


FIGURE 10: Bar chart of loudness ratings for each sound in both background noises

The interrelationships among the various warning attributes are shown in Tables 7 and 8. Table 7 presents the correlation matrix for the 16 acoustic stimuli and Table 8 presents this for the 12 voice stimuli. Intercorrelations among attributes are shown separately for sedan background noise and for truck background noise within each table.

As is evident from the correlation matrix, many of the attribute ratings were strongly correlated. For the acoustic stimuli, muscularity was weakly related to other attributes, and annoyance had some moderate correlations. The other stimuli all correlated with one another at r =0. 85 or greater for the sedan background noise, and at r=0.69 or greater for the truck background noise. Intercorrelations for the voice stimuli tended to be higher than for the acoustic stimuli.

REGRESSION ANALYSIS

The confounding variable of loudness was accounted for by creating scatter plots of stimulus total weighting as a function of loudness rating. Similar plots of specific attribute ratings as a function of loudness ratings also were created for the top four attributes (as determined from the questionnaire) and for the annoyance attribute only. All of the scatter plots incorporated a regression line which described the attribute rating or total weighted rating as a function of the loudness attribute rating. This regression line was used to describe a linear relationship between loudness and each attribute and total weighted score that could then be used to minimize the effects of unequal loudness on data interpretation.

Since in real-life applications, the intensity of a warning signal can be set to any desired level (either by the manufacturer or under control of the user), it would be desirable to compare the performance of the various alternative stimuli in the absence of loudness differences. In this sense, the variation in perceived loudness of the various stimuli may be viewed as a confounding variable. For this reason, regression analyses were conducted, in order to account for the influence of loudness in the overall MAE ratings.

The rationale for the regression analysis is as follows. The total MAE score was intended to provide an index of the “goodness” the potential warning, based on appropriate weighting of the stimulus attributes. Loudness was not an included attribute in the MAE, because it may vary in application. Since, perceptually, loudness did vary from stimulus to stimulus in this experiment, we wished to minimize its influence on the ratings. The regression line in the various scatter plots portrays the general relationship between loudness and the rating. Data points in general fall near this regression line, showing the strong relationship with loudness. Data points that lie above the regression line indicate sounds that are somewhat more highly rated than would be expected based solely on their judged loudness. Data points that lie below the regression line are rated lower than would be expected based solely on their judged loudness. Thus in terms of identifying good candidate warning stimuli, the preference is to use those whose data points lie above the regression line; they are even more effective than their perceived loudness would suggest.

TABLE 7: Correlation matrix for acoustic sounds only (n = 16). Values above the diagonal are for sedan background, values below the diagonal are for truck background.

	AN NO	AP PR	DI SC	EM ER	LO UD	ME AN	MU SI	NR ES	NO TI	ST AR	UR GY
Annoy-ance		.53	.62	.67	.84	.80	-.46	.74	.67	.82	.78
Appropr-iateness	.61		.87	.94	.85	.85	.31	.89	.92	.87	.89
Discrim-inability	.72	.84	--	.95	.85	.88	.27	.92	.95	-90	.90
Emer-gency	.76	.89	.82	--	.88	.91	.22	.95	.95	.93	.94
Loudness	.86	.76	.69	.76		.90	-.05	.89	.89	.96	.93
Meaning	.89	.78	.80	.90	.83	--	-.07	.98	.92	.92	.97
Musical-ity	-.28	.38	.39	.09	-.07	-.12		.04	.17	.03	.04
Natural Response	.86	.81	.76	.94	.86	.96	-.08	--	.95	.93	.97
Notice.-ability	.83	.79	.77	.74	.96	.82	.04	.82	--	.95	.91
Startle	.88	.70	.71	.76	.91	.92	-.19	.89	.91	--	.94
Urgency	.89	.71	.70	.88	.87	.94	-.22	.96	.84	.90	--

Table 8. Correlation matrix for voice sounds only (n = 12). Values above the diagonal are for sedan background, values below the diagonal are for truck background.

	AN NO	AP PR	DI SC	EM ER	LO UD	ME AN	MU SI	NR ES	NO TI	ST AR	UR GY
Annoy-ance		.84	-83	.76	.82	.87	.75	.77	.83	.83	.82
Appropr-iateness	.85		.96	.95	.97	.99	30	.95	.97	.95	.95
Discrim-inability	.93	.96		.98	.95	.98	.94	.97	.99	.95	.98
Emer-gency	.87	.98	.94		.97	.97	.92	.99	.98	.97	.98
Loudness	.86	.98	.96	.96		-96	.91	.98	.97	.98	.96
Meaning	.86	.96	.95	.95	.95		.92	.96	.99	.96	.97
Musical-ity	.48	.76	.65	.69	.71	.76	---	.90	.93	.93	.95
Natural Response	.87	.97	.94	.97	.97	.95	.69	--	.97	.97	.97
Notice-ability	.92	.96	.96	.95	.96	.93	.71	.94	--	.96	.98
Startle	.90	.93	.94	-94	.95	.96	.65	.96	.92	--	.97
Urgency	.84	.96	.92	.98	.95	.95	.66	.97	.91	-93	--

As Figures 11 through 16 suggest, acoustic Stimuli 1, 4, 5 (including 27, 28), 8, and 10 tended to fall above the regression line for total weighting and for the key positive attributes. Stimuli 4, 5, 8, and 10 also fell below the regression line for the negative factor of annoyance. For the voice stimuli (see Figures 17 through 22), data points clustered more closely around the regression line, so that there was less apparent effect of voice/message type beyond the perceived loudness. Only voice Stimuli 15 and 20 tended to be consistently above the regression line. Appendix J and Appendix K contain the scatter plots for acoustic warnings and voice warnings in the truck background noise condition.

SELECTION OF PREFERRED WARNING STIMULI

Based on the MAE scores and the regression analyses, a subset of the stimuli was selected as preferred for subsequent research and application. Among the acoustic warnings, Stimuli 1, 5, 8, and 10 scored highly on the total MAE weighting in the sedan background. These stimuli, together with Stimulus 4, also tended to be more effective than their loudness alone would suggest. Therefore, taking these two criteria (total MAE and regression analysis) together, the acoustic stimuli that merit further consideration are 1, 5, 8, and 10. Among these, Stimulus 1 was the most annoying, both in terms of absolute rating and also relative to the regression line. At the same time, the total MAE weighting for Stimulus 1 was the highest in the set, both in absolute terms and relative to the regression line.

The five most effective stimuli (numbers 1, 4, 5, 8 and 10) had some features in common. With the exception of Stimulus 1 (low-fuel aircraft warning), the majority of these stimuli had frequency spectra that showed relatively high frequency energy, and exhibited multiple harmonious peaks above a fundamental basic tonal component. They all had multiple bursts or pulses in their time histories, which gave them a time-varying or intermittent character. Stimulus 1 had predominantly high-frequency acoustic energy, but of a more spread out spectrum, minus the distinct harmonics which are multiples of some fundamental tone.

Findings for the voice stimuli are less clear. As a class, the voice sounds were somewhat less effective than the (non-voice) acoustic sounds. Within the voice sounds, the digitized voices were rated considerably louder than the synthesized voices, complicating the interpretation. In general, the digitized voices had higher total MAE weightings, but the loudness rating accounts for most of this. Generally, the "DANGER" message had a higher MAE weighting, but again this was strongly related to loudness. Since the word message can be independent of the voice used, there is no strong basis for excluding any of the four voices from further evaluation. However, the female synthesized voice may be the weakest of these choices, unless it is presented at substantially higher sound levels than other voice stimuli. This stimulus tended to suffer a loss of conspicuity in truck noise, relative to sedan noise, as well.

Figure 11: **Total Weighted x Loudness, Sedan Background, Acoustic Stimuli**

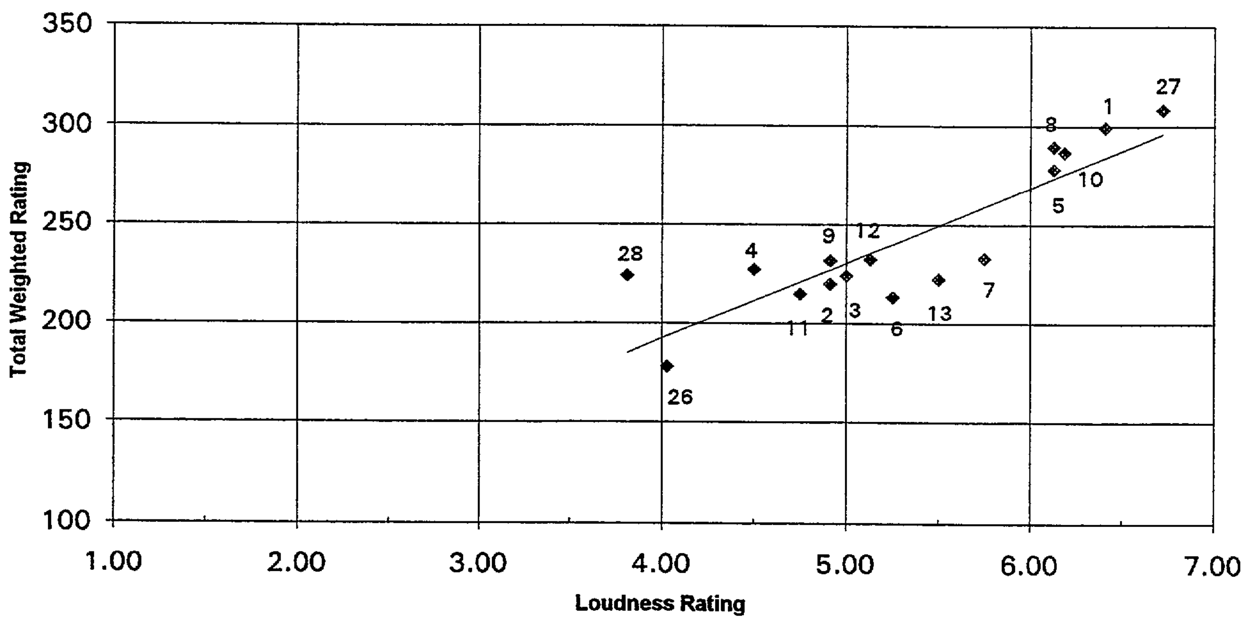


Figure 12 : Noticeability x Loudness, Sedan Background, Acoustic Stimuli

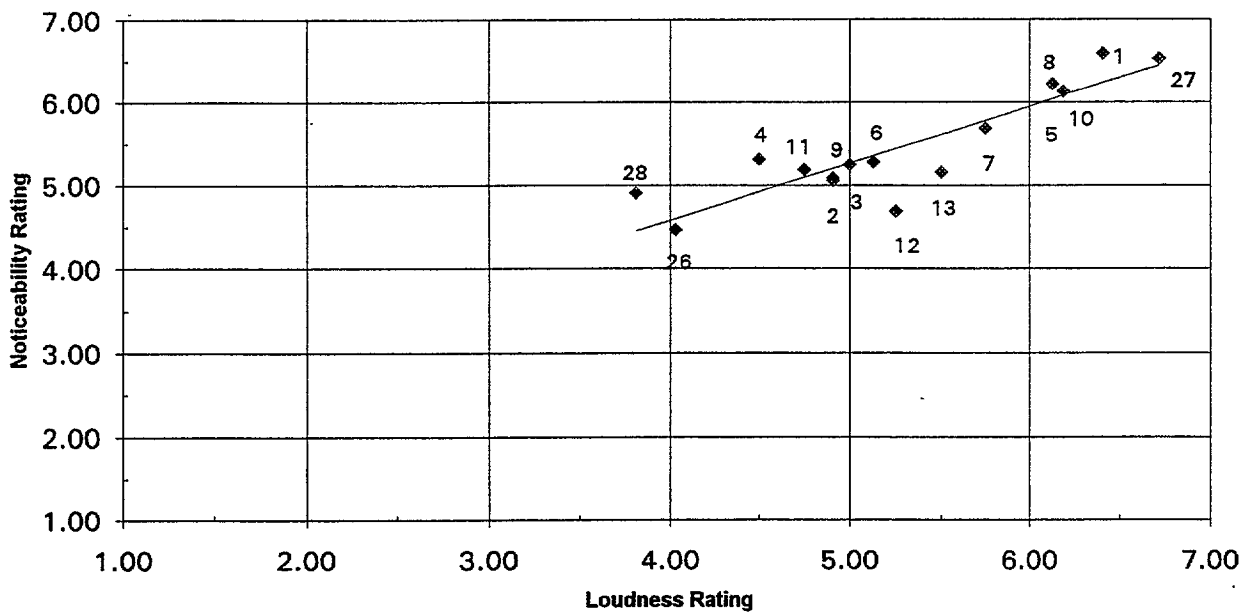


Figure 13 : Discrimination x Loudness, Sedan Background, Acoustic Stimuli

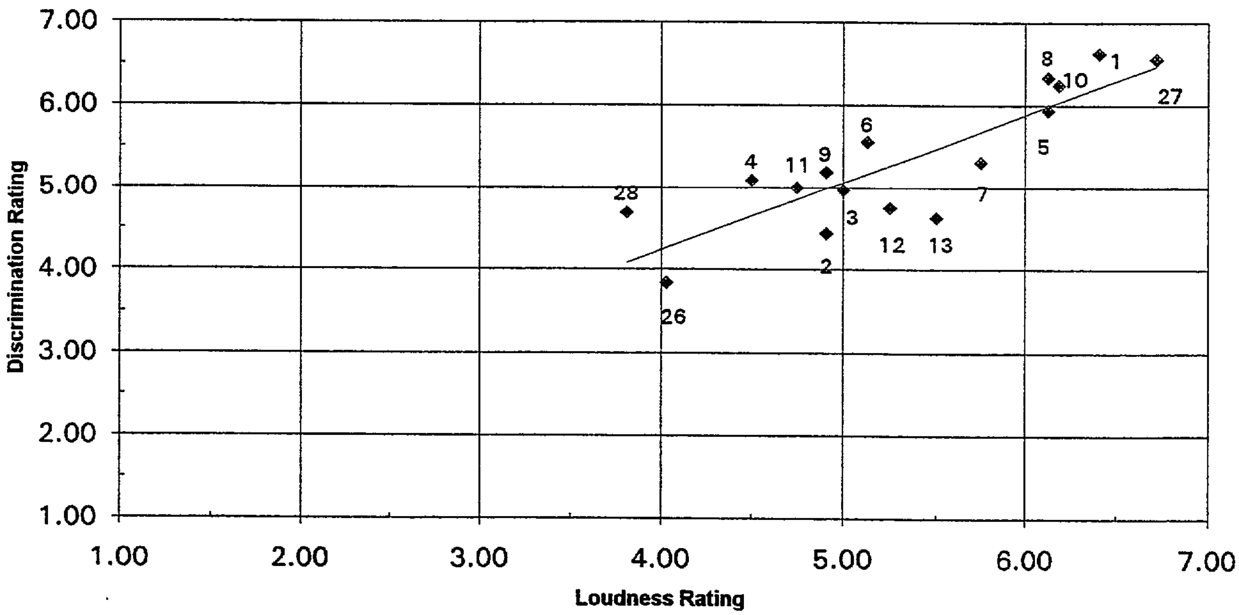


Figure 14 : Meaning x Loudenss, Sedan Background, Acoustic Stimuli

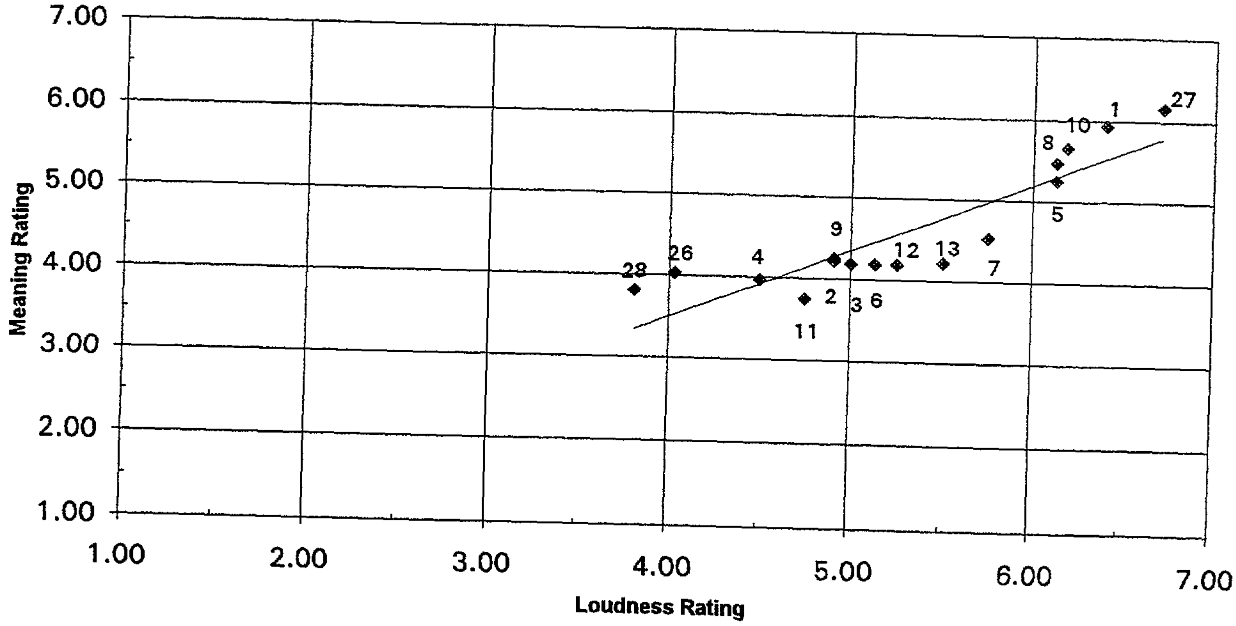


Figure 15: Urgency x Loudness, Sedan Background, Acoustic Stimuli

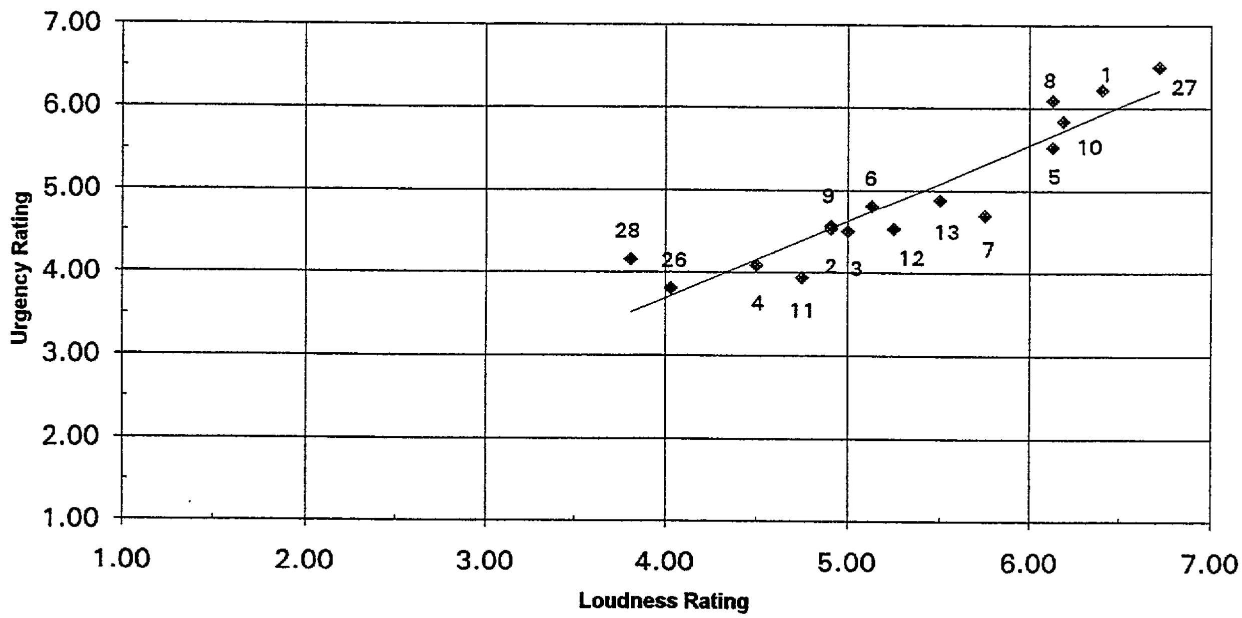


Figure 16: Annoyance x Loudness, Sedan Background, Acoustic Stimuli

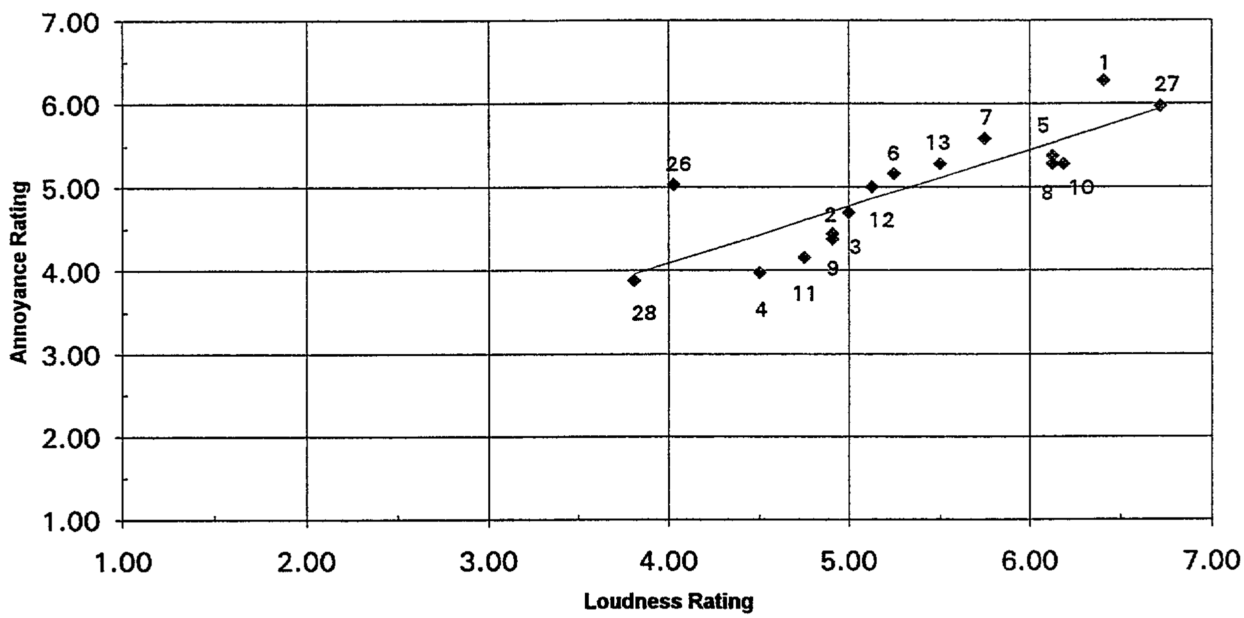


Figure 17: Total Weighted x Loudness, Sedan Background, Voice Stimuli

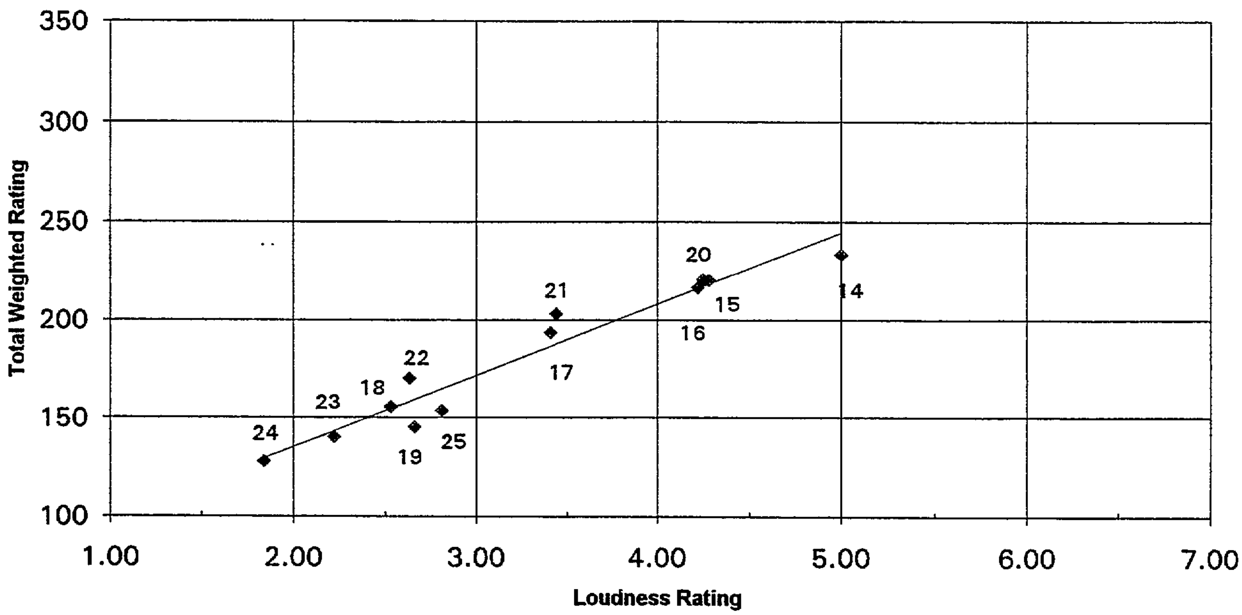


Figure 18: Noticeability x Loudness, Sedan Background, Voice Stimuli

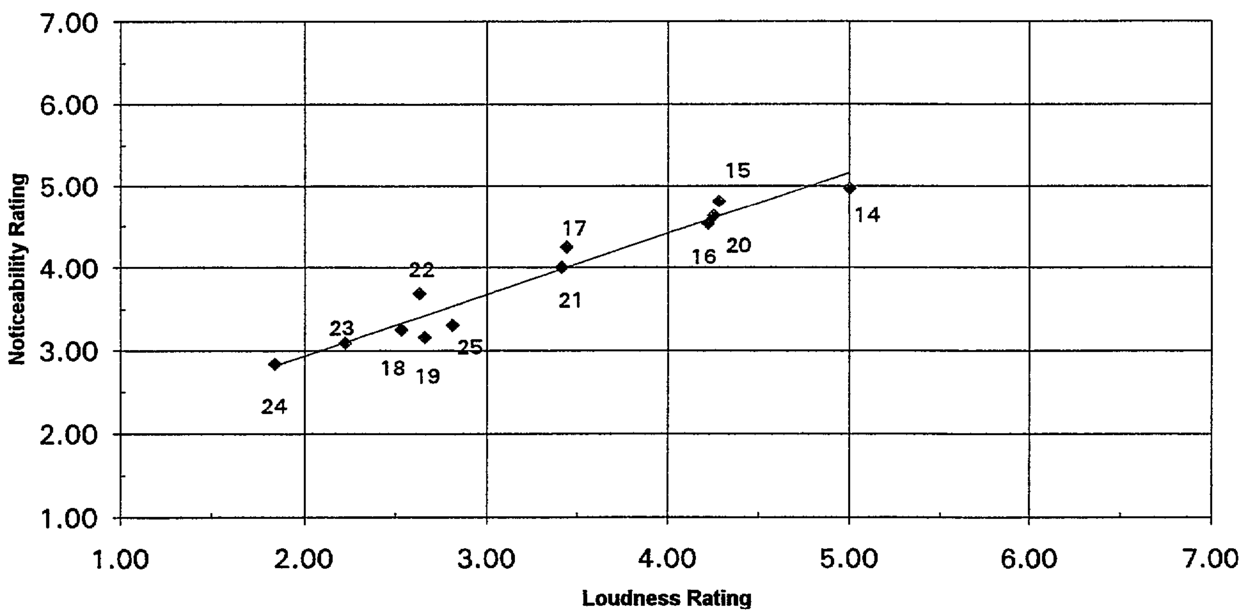


Figure 19: Discrimination x Loudness, Sedan Background, Voice Stimuli

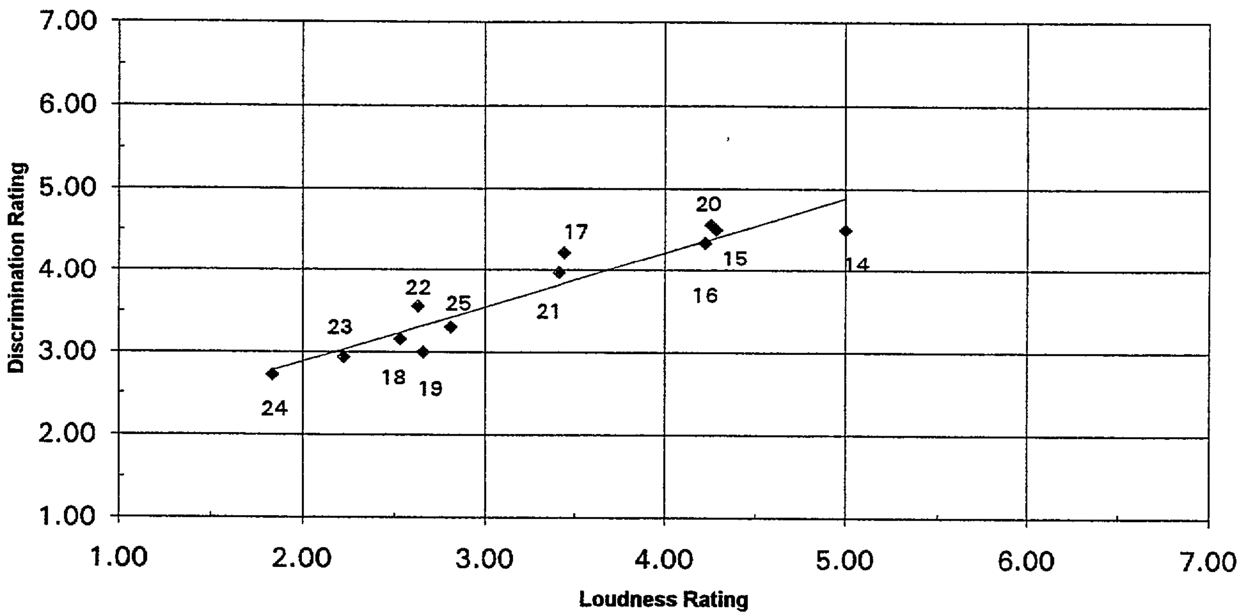


Figure 20: Meaning x Loudness, Sedan Background, Voice Stimuli

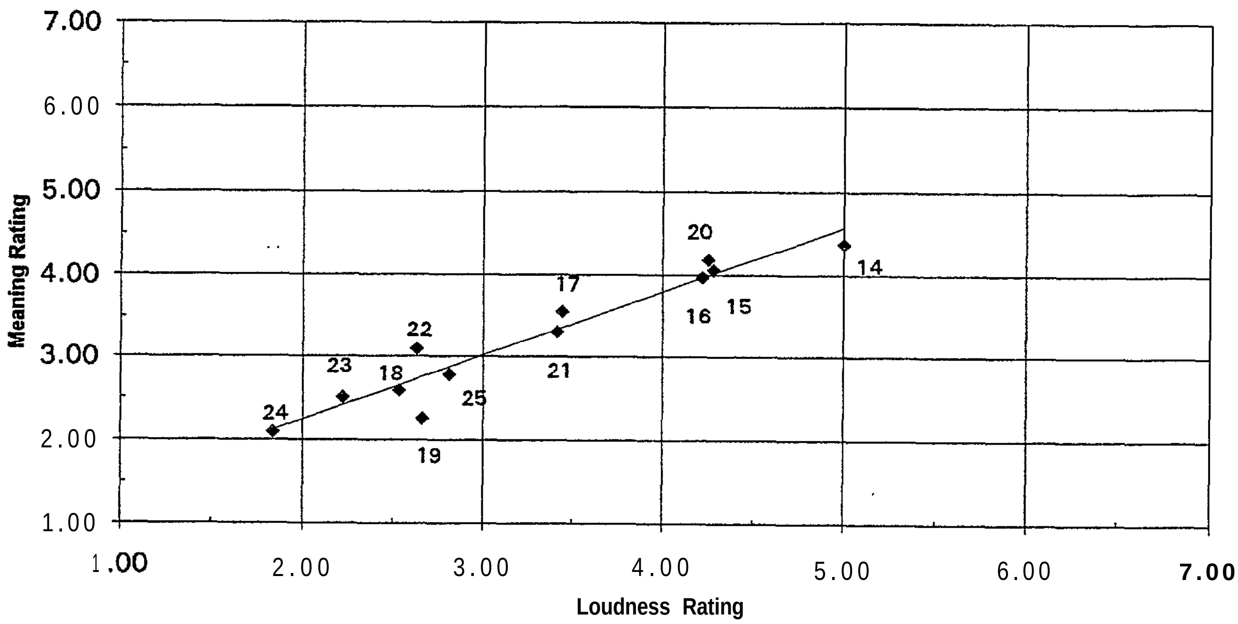


Figure 21: Urgency x Loudness, Sedan Background, Voice Stimuli

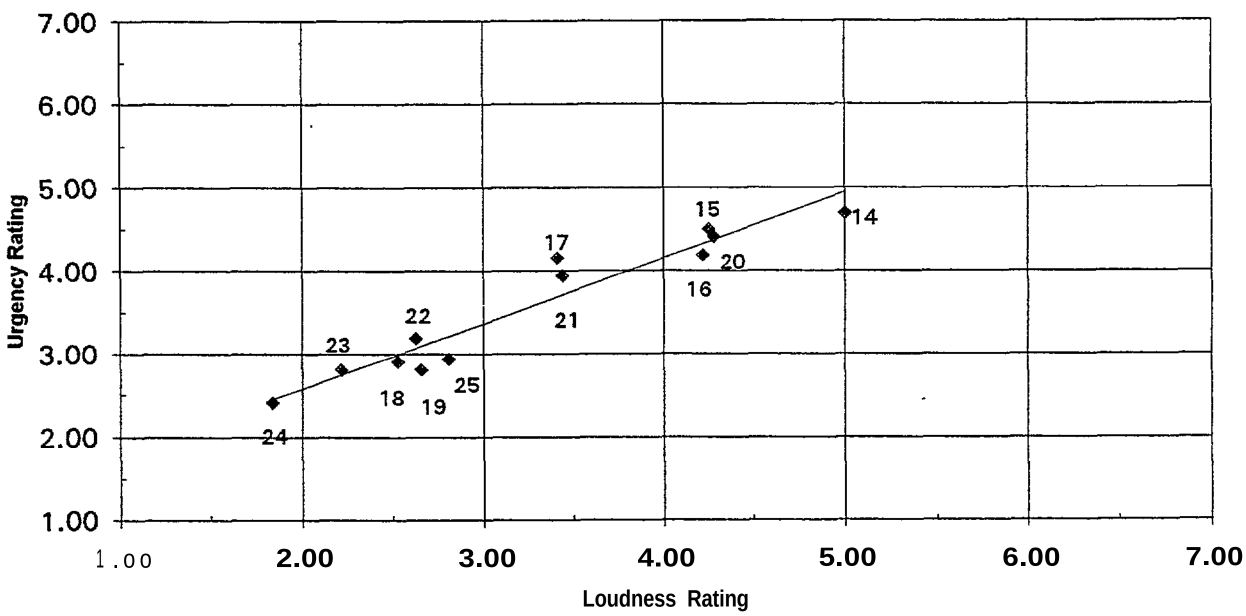
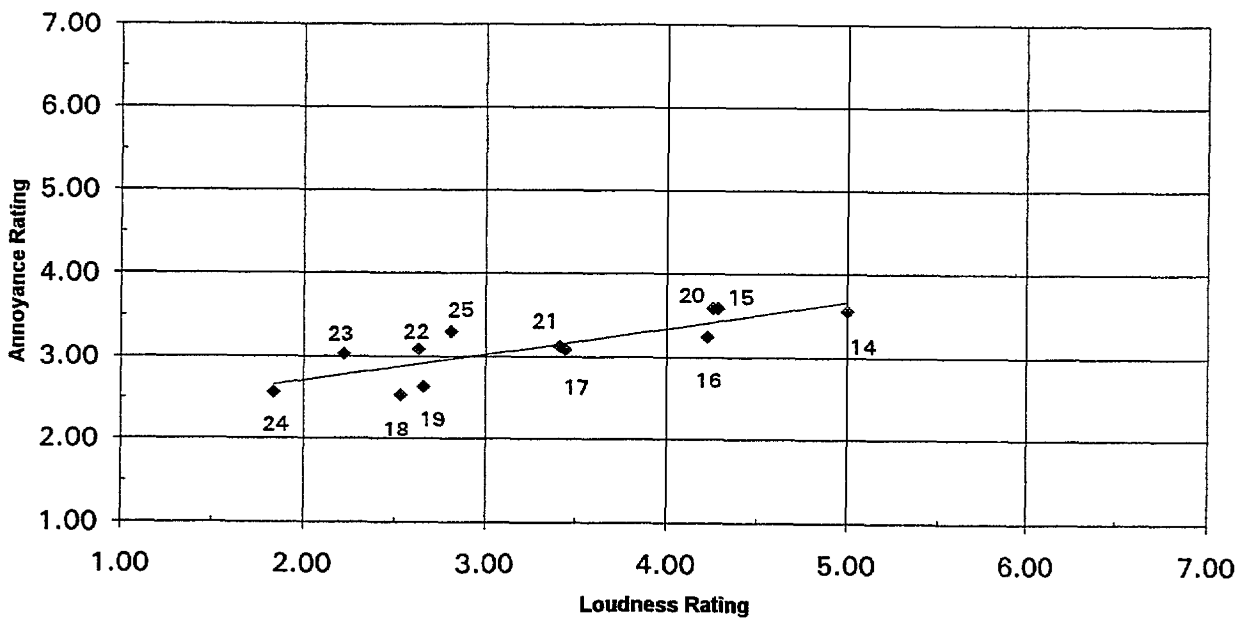


Figure 22: Annoyance x Loudness, Sedan Background, Voice Stimuli



CONCLUSIONS

This research included the following sequence of steps: it identified key attributes of auditory warning signals; established relative weightings for each of those attributes; collected subjective ratings for each attribute for a set of potential crash avoidance warning sounds; applied the weightings to the ratings to evaluate each sound; and identified a most-promising subset of sounds. The experimental study was successful in identifying four acoustic signals as preferred over others for in-vehicle application. Findings for voice messages were less clear, since no voice stood out as clearly better, once the possible confounding effect of subjective loudness was taken into account. Nonetheless, the data did reveal that the acoustic (non-voice) sounds generally performed somewhat better in total rating scores than did the voice sounds.

The intent of this research was to optimize the auditory warnings that may be used in future crash avoidance warning applications. There is a need to standardize such warnings, so that they retain immediacy of meaning across various vehicles, situations, and hazards. The current fmdings contribute to an empirical basis upon which such decisions may be made, so that an effective warning stimulus is ensured. The best-performing stimuli in this study can be considered reasonable candidate signals. Since this study could only evaluate a finite set of stimuli, from an infinite number of alternatives, it is not meaningful to view this research as defining the best possible warning signal. However, the study does define those stimuli in the set that were relatively more effective, and based on other criteria from the literature, should be reasonable candidates for selection.

One factor that complicated the analysis of the data was that the subjective loudness of the various signals varied. This would be appropriate if loudness was one of the sound attributes under consideration; however, since loudness can be adjusted for any sound, the intent was to evaluate alternative sounds independent of their loudness. Although the stimuli were equated for presentation in the laboratory at equivalent A-weighted sound levels, or dB(A), readings, this did not preclude variations in the subjective level of loudness. A linear regression analysis was used to statistically minimize the confounding effect of subjective loudness. However, it is recommended that future research should equalize stimuli in terms of subjective loudness prior to conduct of any experiment. This can be done through the use of psychophysical methods using small juries. However, it is also recommended that subjective loudness ratings be acquired during the experiment as well as was done here, so that ***post*** hoc analysis can confirm the equalization and deal with any variances.

APPENDIX A: MAE QUESTIONNAIRE

comsis

8737 COLESVILLE ROAD, SUITE 1100
SILVER SPRING, MARYLAND 20910
(30 1) 588-0800
FAX: (301) 588-5922

(MONTH DAY, YEAR)

{NAME}
(ADDRESS)
{CITY, STATE ZIP)

Dear (FIRST NAME):

Thank you for participating in this survey. We appreciate your time and your interest in our study. As you may recall, the human factors group at COMSIS is conducting a survey of what experts in the fields of IVHS, safety, and human factors consider to be important perceptual attributes of auditory warnings for in-vehicle crash avoidance warning applications. We would like to survey your opinion on this topic.

The survey is part of a research project on Crash Avoidance Warning Devices that is being sponsored by the National Highway Traffic Safety Administration (NIITSA). Our initial task was to develop preliminary human factors guidelines for these devices. Based on the guidelines, we are currently researching auditory warnings for use with these devices. This survey is designed to help us identify auditory warning attributes (e.g. urgency, conspicuity, etc.) that are reliable indicators of a warning's effectiveness as an in-vehicle collision avoidance device warning. That is, a warning to alert a driver that a crash situation is likely unless an immediate action is taken. Expert opinions of these attributes will allow us to select physical characteristics (e.g. wave form features) that are best suited for providing the desired percepts.

Enclosed is the survey we would like you to complete. When you have completed the survey please return it in the enclosed envelope. If you have any questions, please call Adrian Tan at (301) 588-0810 x8017.

Thank you again for your time and input given to this survey.

Sincerely,

R. D. Lyons, Ph.D.
Manager, Human Systems Design

Enclosure:

SURVEY OF AUDITORY WARNING ATTRIBUTES FOR IN-VEHICLE COLLISION AVOIDANCE DEVICES

METHODOLOGY

The key to identifying optimal auditory warnings is to realize that the warnings are not one-dimensional hut have multiple attributes. In some cases these attributes are even counter to each other (e.g. attention getting vs. annoying). This research recognizes that auditory warnings are not one-dimensional. Thus, a Multi-Attribute Evaluation (MAE) technique will be used to assess the warnings. Multi-Attribute Evaluation offers a systematic method of evaluating complex items having multiple traits. The MAE integrates divergent attributes of an item into a single score to enable the items to be directly compared to one another. This methodology requires defining and weighting key attributes on which the items will be evaluated. We are surveying expert judgements to define and provide weightings for the perceptual attributes of auditory warning signals,

INSTRUCTIONS

You will be rating perceptual attributes associated with auditory warnings. These attributes will be considered in the development of a collision avoidance warning for an in-vehicle collision avoidance system. The purpose of this auditory warning is to inform the driver of an "imminent crash" situation, which means that a crash will occur unless an immediate action is taken on the part of the driver. The warnings can be either acoustic (e.g. warble, constant tone, etc.), vocal (e.g. "Warning!", "Caution!", etc.), or a combination of both.

While each of the attributes listed in the survey is probably important to auditory warning design, the purpose of this survey is to evaluate the relative importance of each attribute. Specifically, given a design situation where trade-offs are unavoidable, how much weight should be given to each of these attributes when creating or selecting a warning? Note that the interest of this survey is on the perceptual attributes of the warning and not the physical characteristics of the warning that create these attributes, such as frequency sweep, duty cycle, and intensity.

On the following page there are twelve attributes to be rated. Please review all the attributes and their definitions prior to performing your ratings. You will be rating the attributes on a scale from 1 to 10, where a "10" indicates that the attribute is extremely important. Please circle the number corresponding to your rating. You may assign the same rating to more than one attribute. All or most of these attributes probably have some importance. However, your ratings should show the relative importance when these factors are compared to each other.

The last page is for additional attributes that you feel should also be included. Please provide brief descriptions as well as ratings of importance relative to the existing attributes. After you make any suggestions, please complete the rank ordering task. There is a blank page included for additional comments you might have.

Thank you for your participation!

AUDITORY WARNING ATTRIBUTE RATINGS

Relative to each other, how important are these attributes to an auditory warning? Please circle.

CONSPICUITY Trivial 1 2 3 4 5 6 7 8 9 10 -- Very Critical
The auditory warning is noticeable within other noises and sounds in the vehicle.

DISCRIMINABILITY Trivial 1 2 3 4 5 6 7 8 9 10 --Very Critical
The auditory warning is uniquely identifiable and distinct from other sounds in the driving environment.

MUSICALITY Trivial -- 1 2 3 4 5 6 7 8 9 10 ---Very Critical
The auditory warning is melodious.

MEANING Trivial --- 1 2 3 4 5 6 7 8 9 10 --Very Critical
The auditory warning unambiguously conveys or suggests the meaning of "imminent crash".

URGENCY Trivial -- 1 2 3 4 5 6 7 8 9 10 -- Very Critical
The auditory warning conveys the proper sense of importance motivating an immediate response.

APPROPRUTENJZSS Trivial --1 2 3 4 5 6 7 8 9 10 ---Very Critical
The auditory warning is compatible with the vehicle environment,

ANNOYANCE Trivial – 1 2 3 4 5 6 7 8 9 10 — Very Critical
The auditory warning is NOT annoying or irritating to the driver (assuming minimal false alarm rates).

STARTLE EFFECTS Trivial --- 1 2 3 4 5 6 7 8 9 $0 --- Very Critical
The auditory warning DUES NOT startle or surprise the driver causing a delayed reaction.

NATURALNESS Trivial --- 1 2 3 4 5 6 7 8 9 10 —Very Critical
The auditory warning DOES NOT appear artificial or computer gererated.

EXPERIENCE COMPATIBILITY Trivial- 1 2 3 4 5 6 7 8 9 10 — Very Critical
The auditory warning Follows natural or learned relationships of users, such as sirens associated with emergency, or words such as "DANGER" and "CAUTION" associated with warnings.

ORIENTING RESPONSE Trivial ← 1 2 3 4 5 6 7 8 9 10 → Very Critical
The auditory warning can be easily localized in 3-D sound space, and causes the driver to look in the direction of the hazard.

RESPONSE COMPATIBILITY Trivial --- 1 2 3 4 5 6 7 8 9 10 — Very Critical
The auditory warning causes the driver to anticipate and prepare for an emergency response

AUDITORY WARNING ATTRIBUTE SUGGESTIONS

Please describe and rate additional attributes you feel we might have overlooked

1. ______________________ **Trivial — 1 2 3 4 5 6 7 8 9 10 — Very Critical**

Description:

2. ______________________ **Trivial -- 1 2 3 4 5 6 7 8 9 10—Very Critical**

Description:

3. ______________________ **Trivial -- 1 2 3 4 5 6 7 8 9 10 ---Very Critical**

Description

4. ______________________ **Trivial- - 1 2 3 4 5 6 7 8 9 10 --Very Critical**

Description:

RANK ODERING TASK

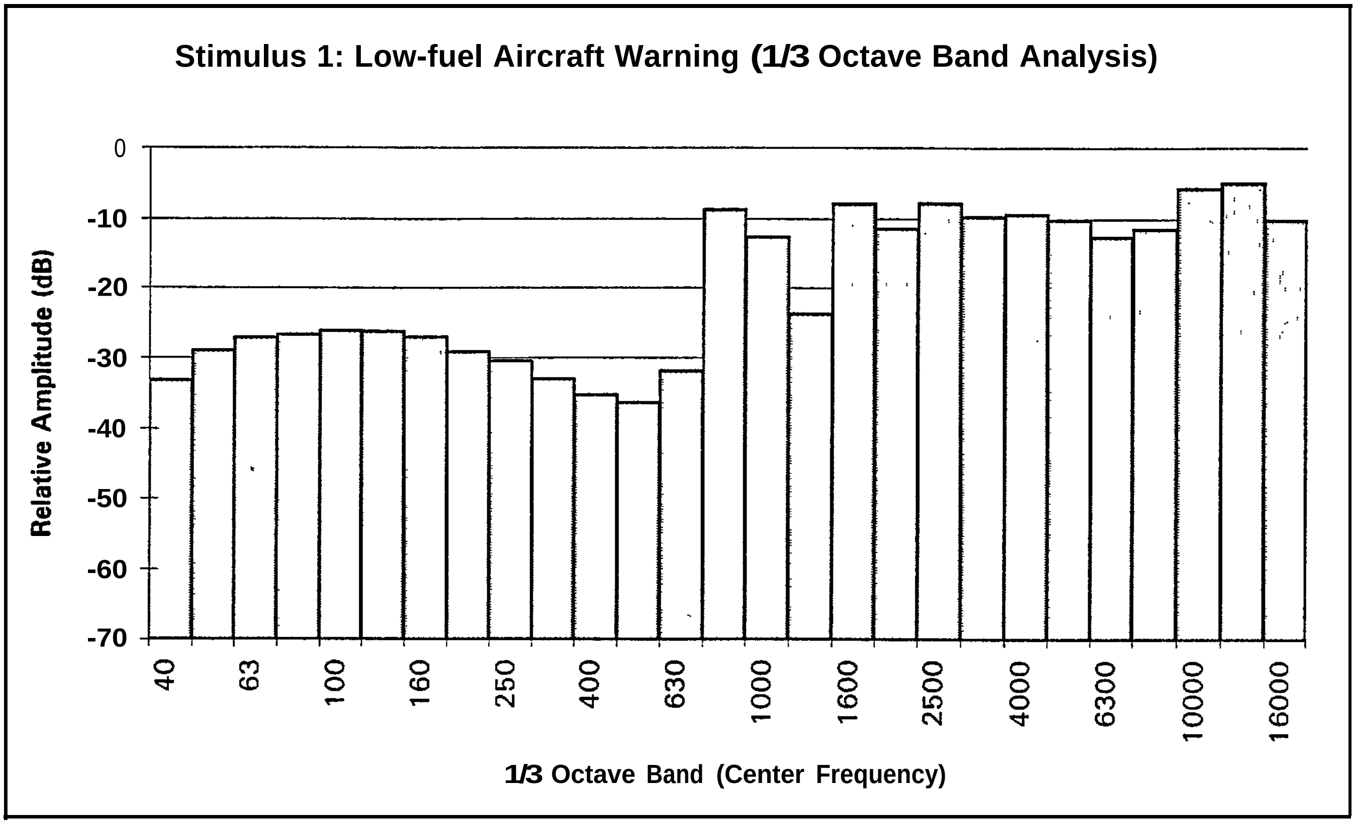
Please rank **order the following attributes, together with any additional attributes you may want to include, on the basis of overall importance (1 = most 'Important).**

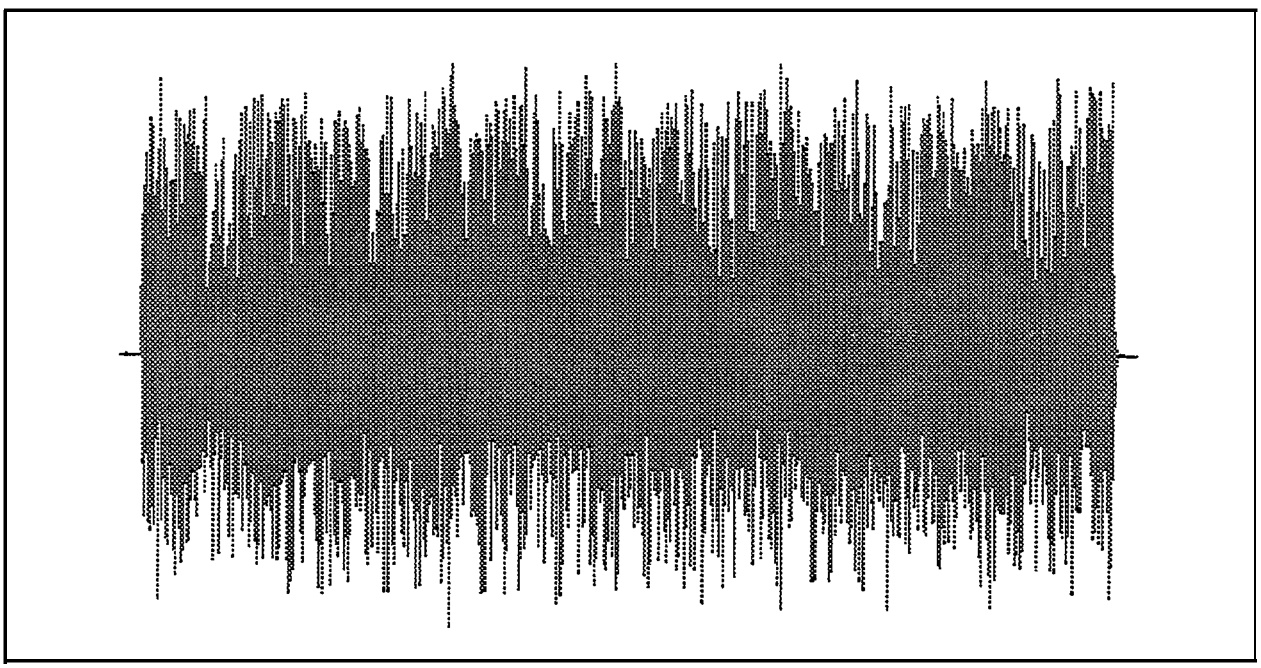
_____ **Urgency**
_____ Appropriateness
_____ Response Compatibility
_____ Conspicuity
_____ Musicality
_____ Experience Compatibility
_____ Annoyance Level
_____ Naturalness
_____ Orienting Response
_____ Meaning
_____ Startle Effects
_____ Discriminability
_____ ______________________
_____ ______________________
_____ ______________________
_____ ______________________

WE WELCOME ANY COMMENTS YOU MIGHT HAVE.

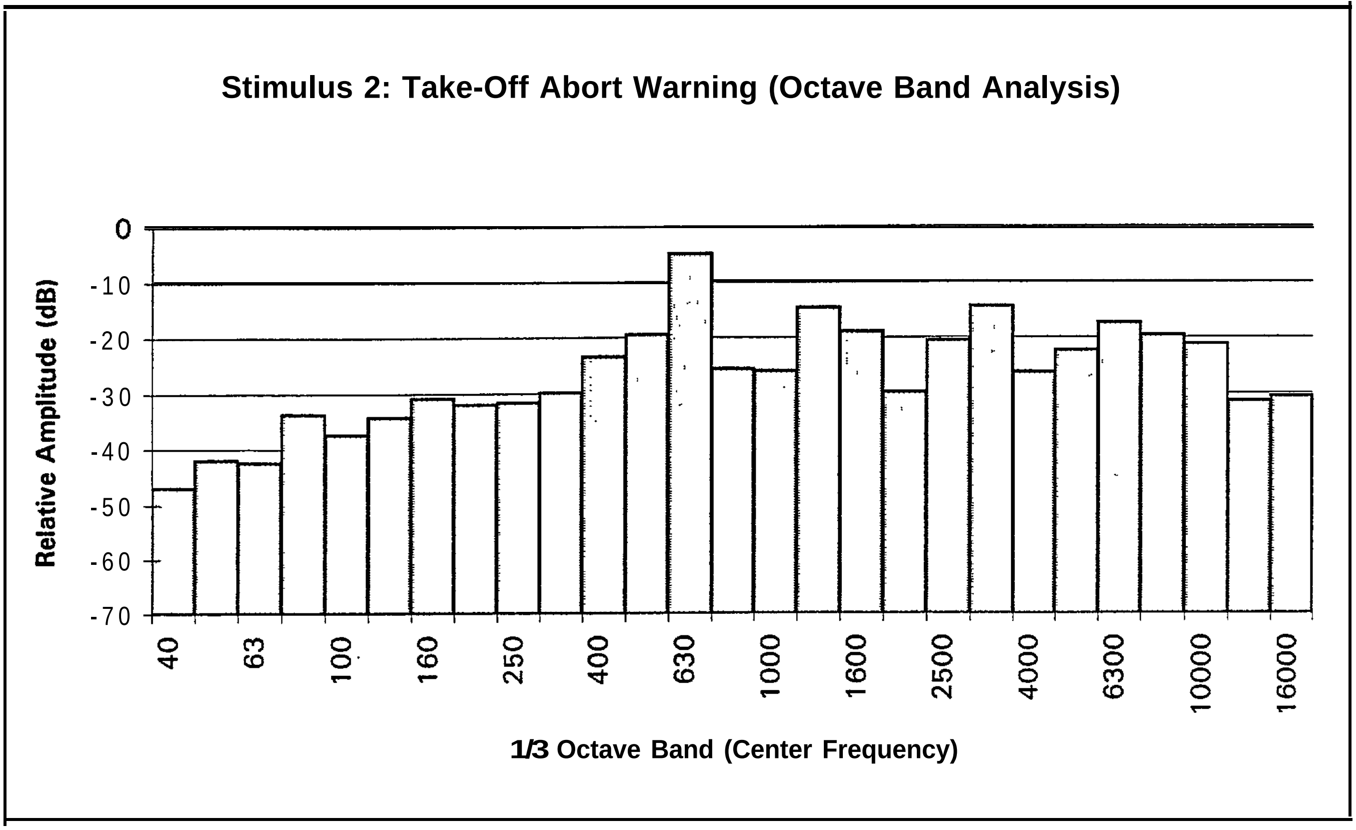
Thank You.

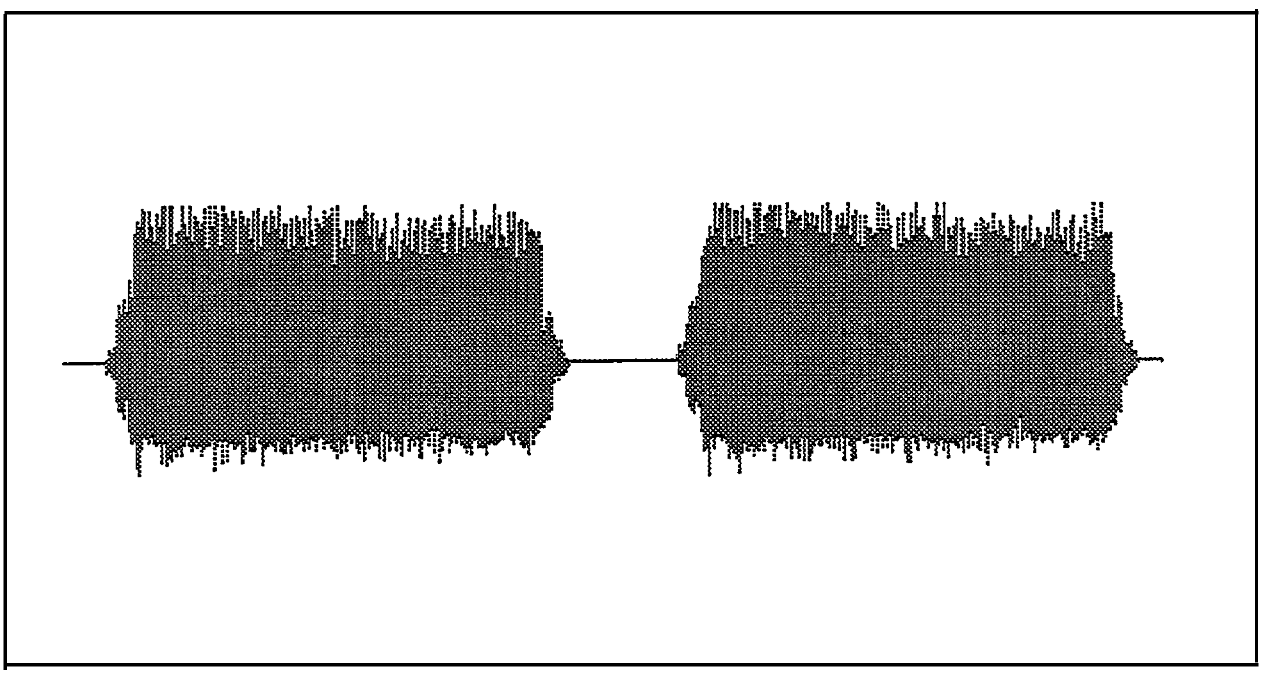
APPENDIX B: OCTAVE BAND AND TIME SERIES ANALYSIS OF EACH STIMULUS


Stimulus 1: Low-fuel Aircraft Warning (1/3 Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)

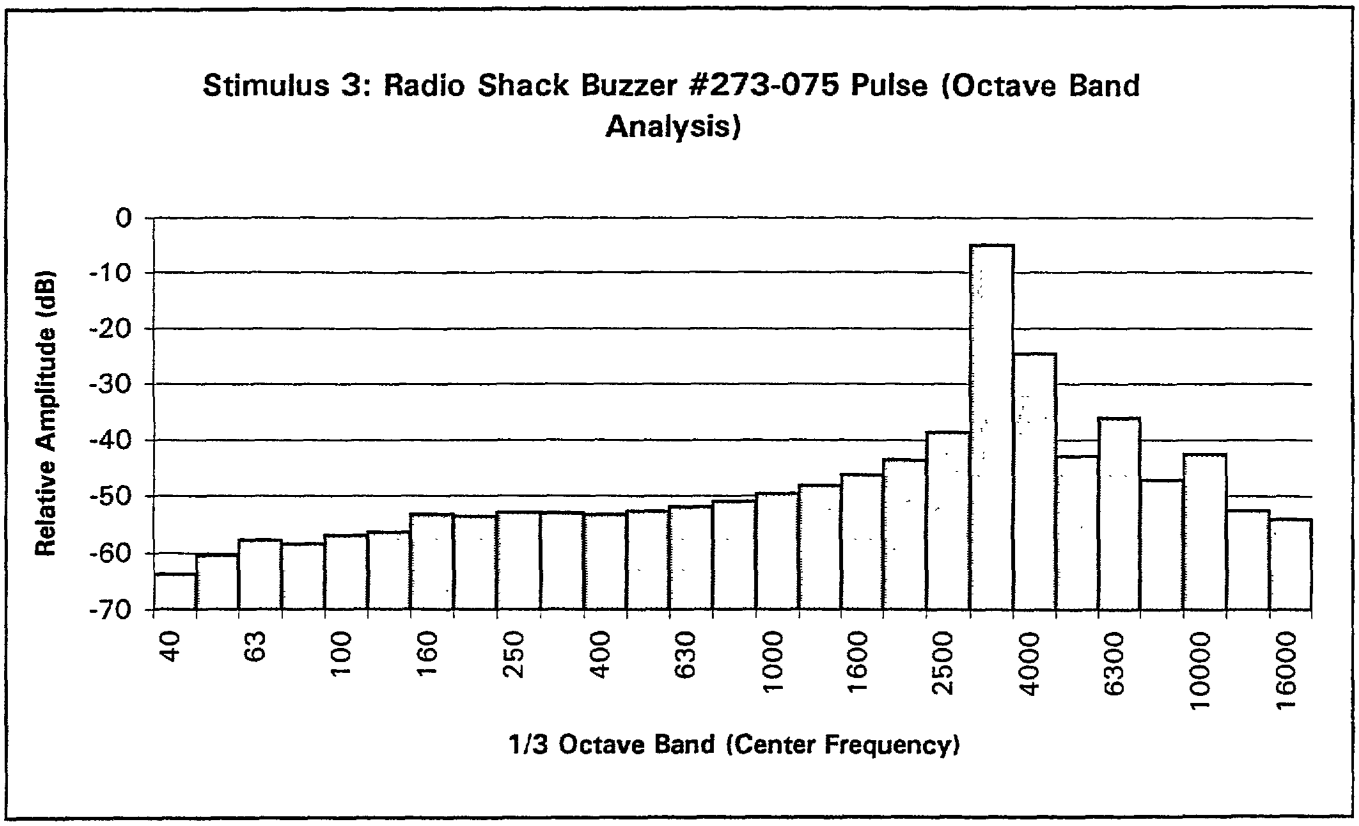


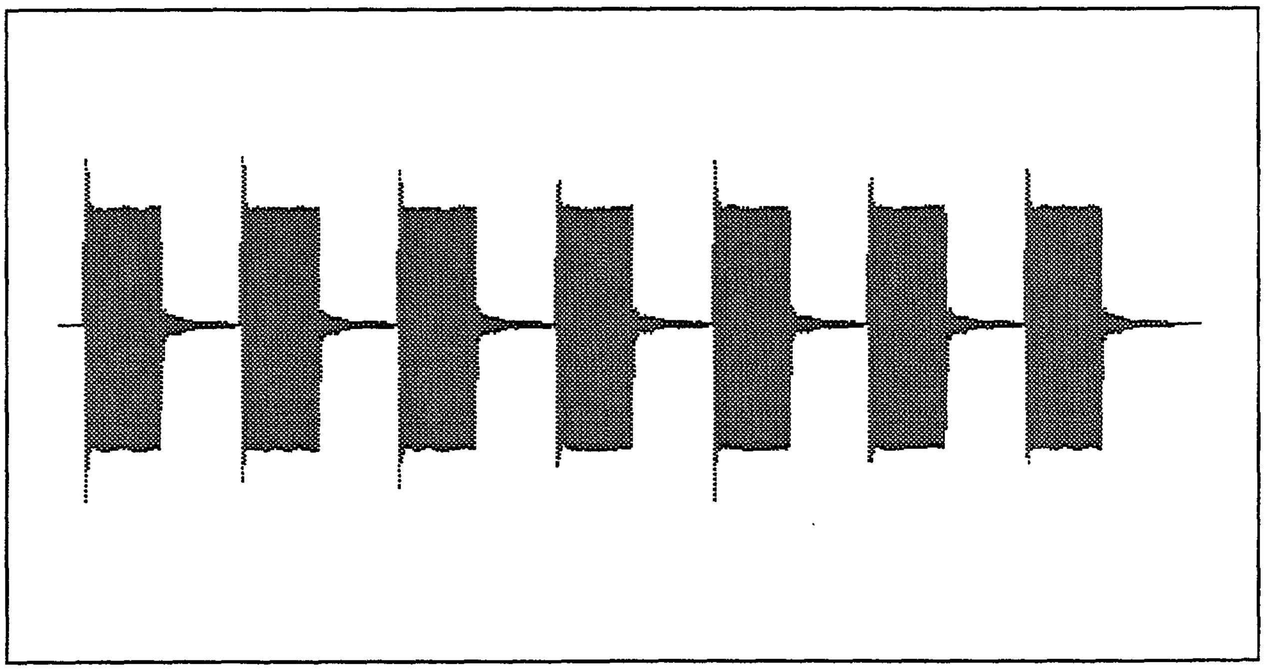
Stimulus 1


Stimulus 2: Take-Off Abort Warning (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)

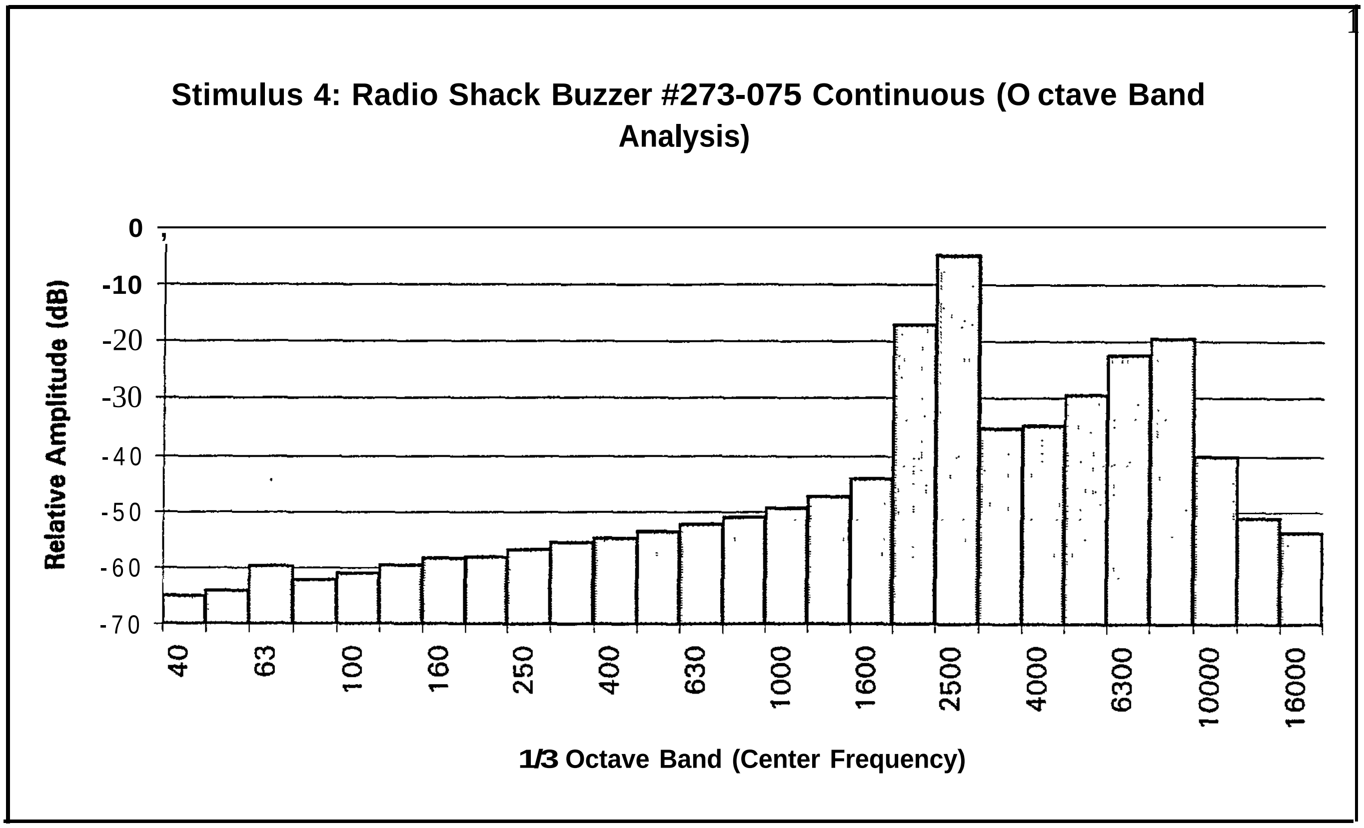


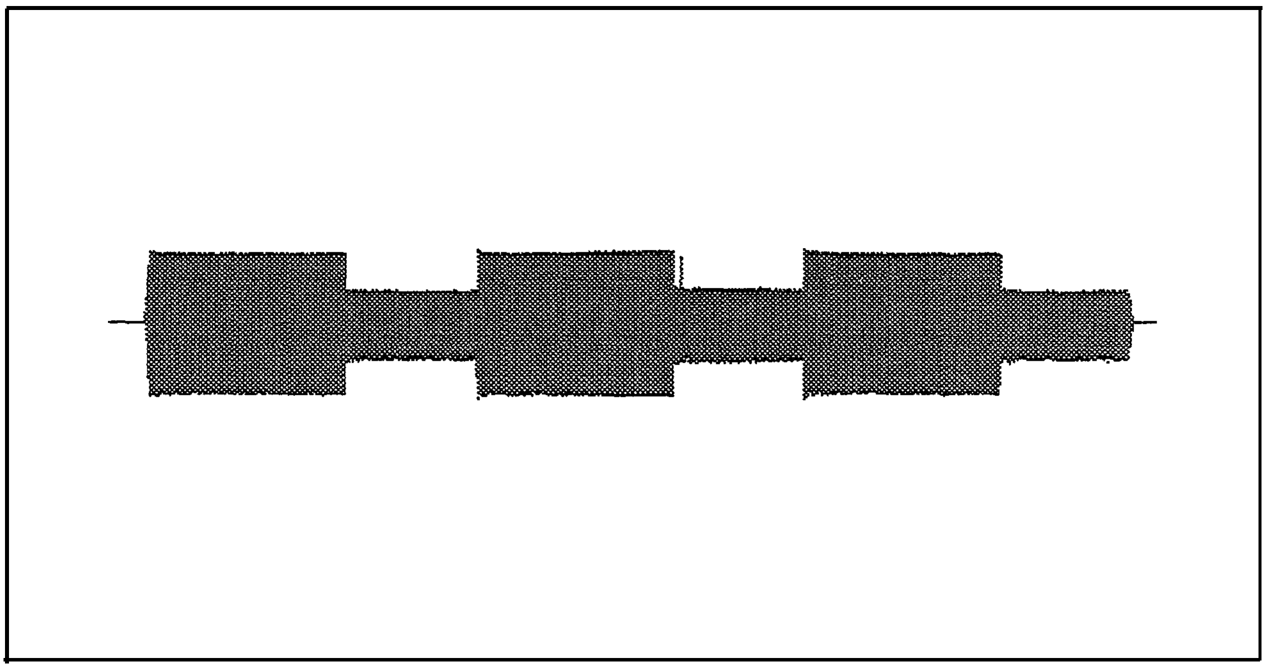
Stimulus 2


Stimulus 3: Radio Shack Buzzer #273-075 Pulse (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)

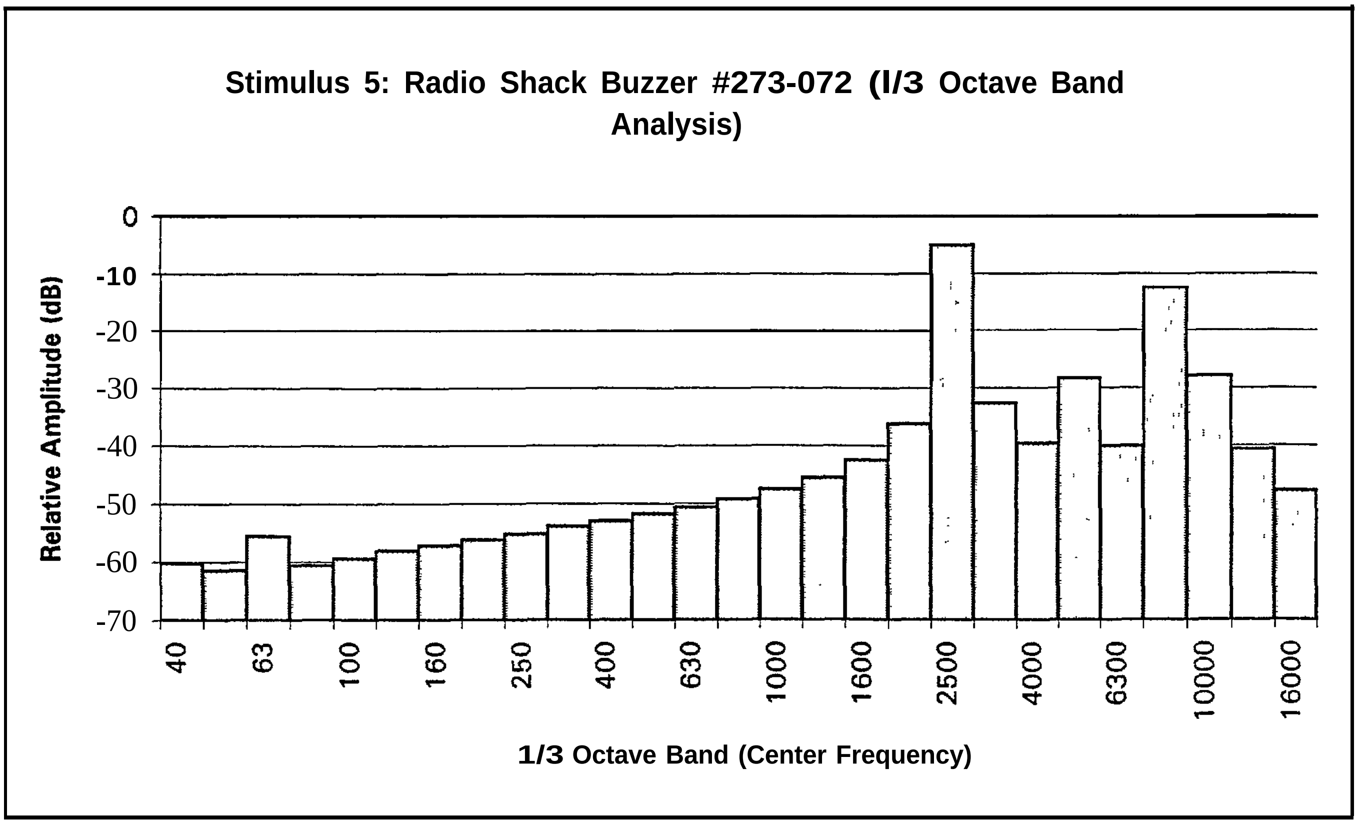


Stimulus 3

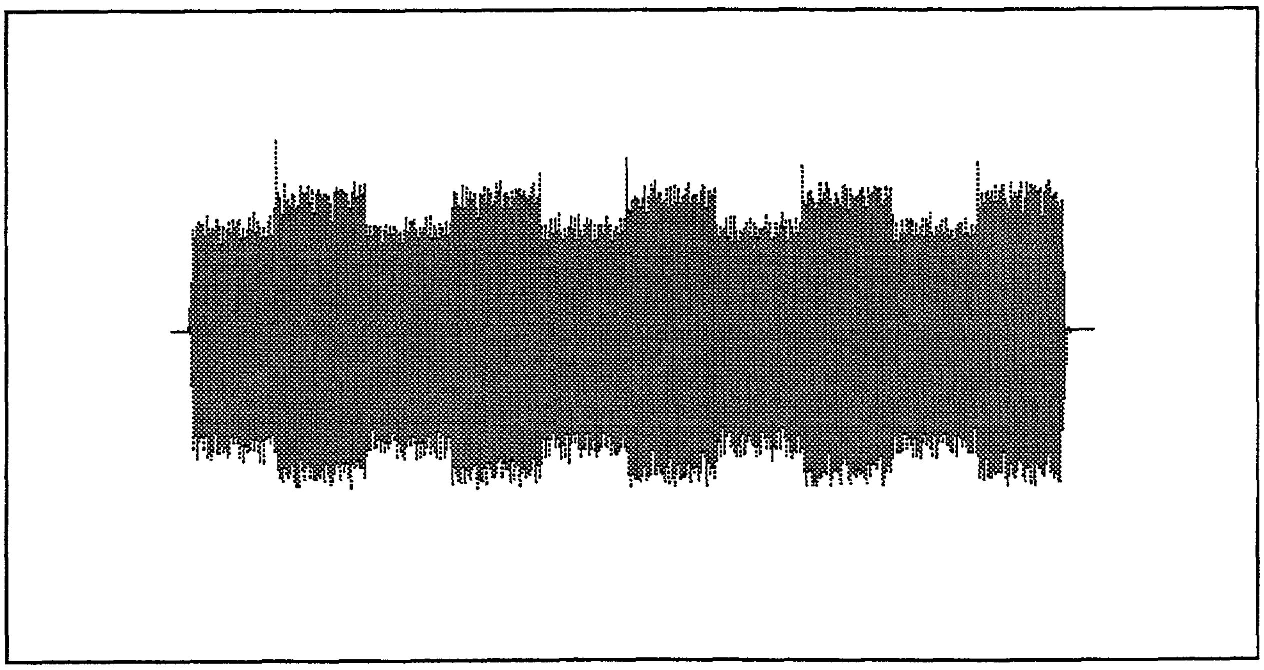

Stimulus 4: Radio Shack Buzzer #273-075 Continuous (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)



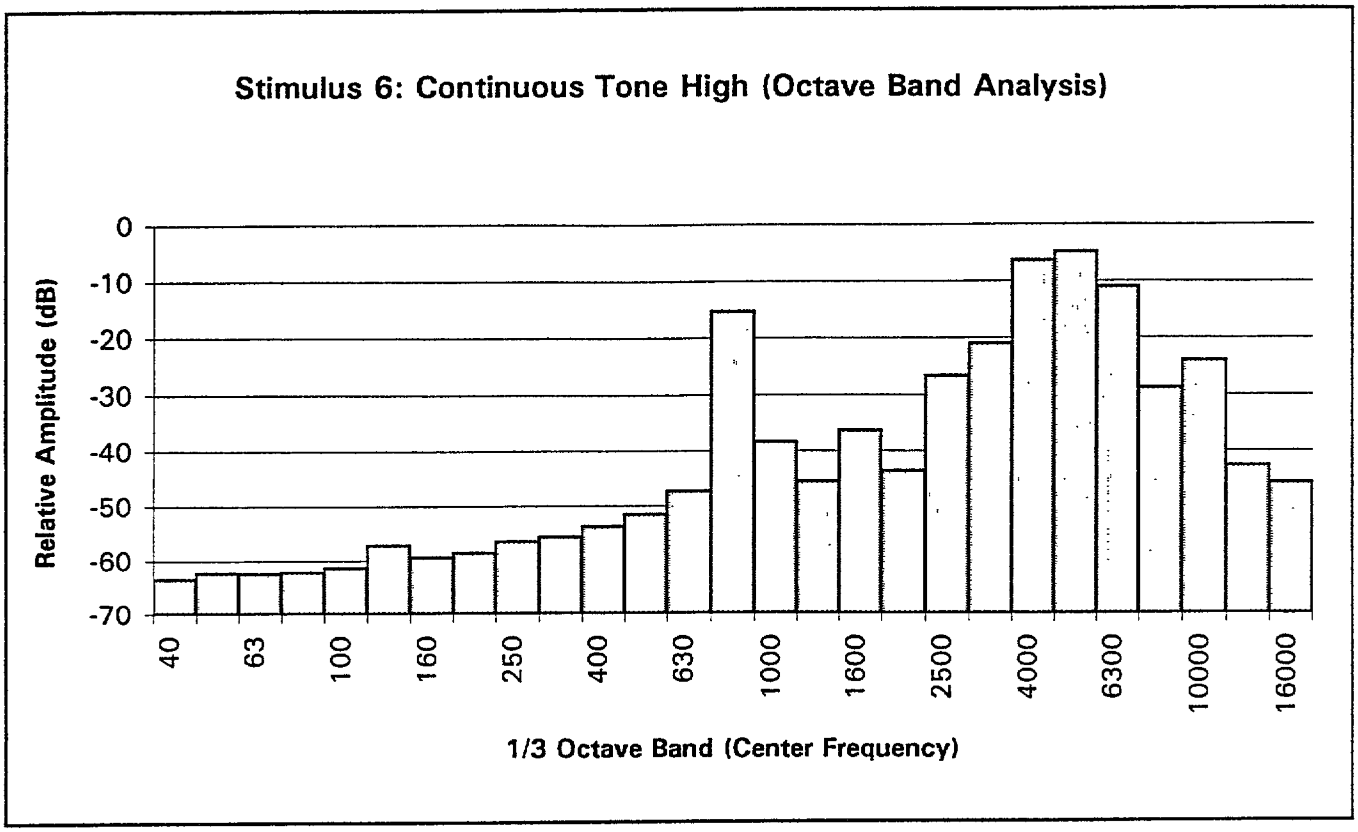
Stimulus 4

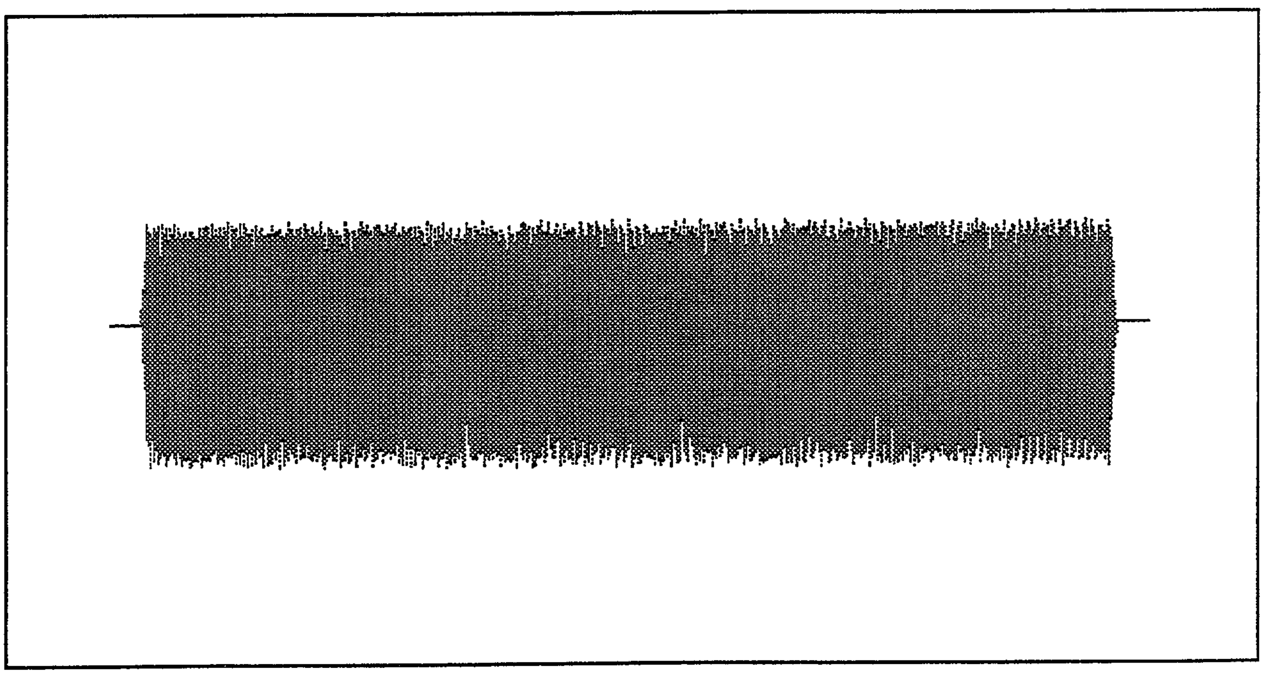


Stimulus 5: Radio Shack Buzzer #273-072 (l/3 Octave Band Analysis)
0
-10
-20
-30
-40
-50
-60
-70
Relative Amplitude (dB)
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)

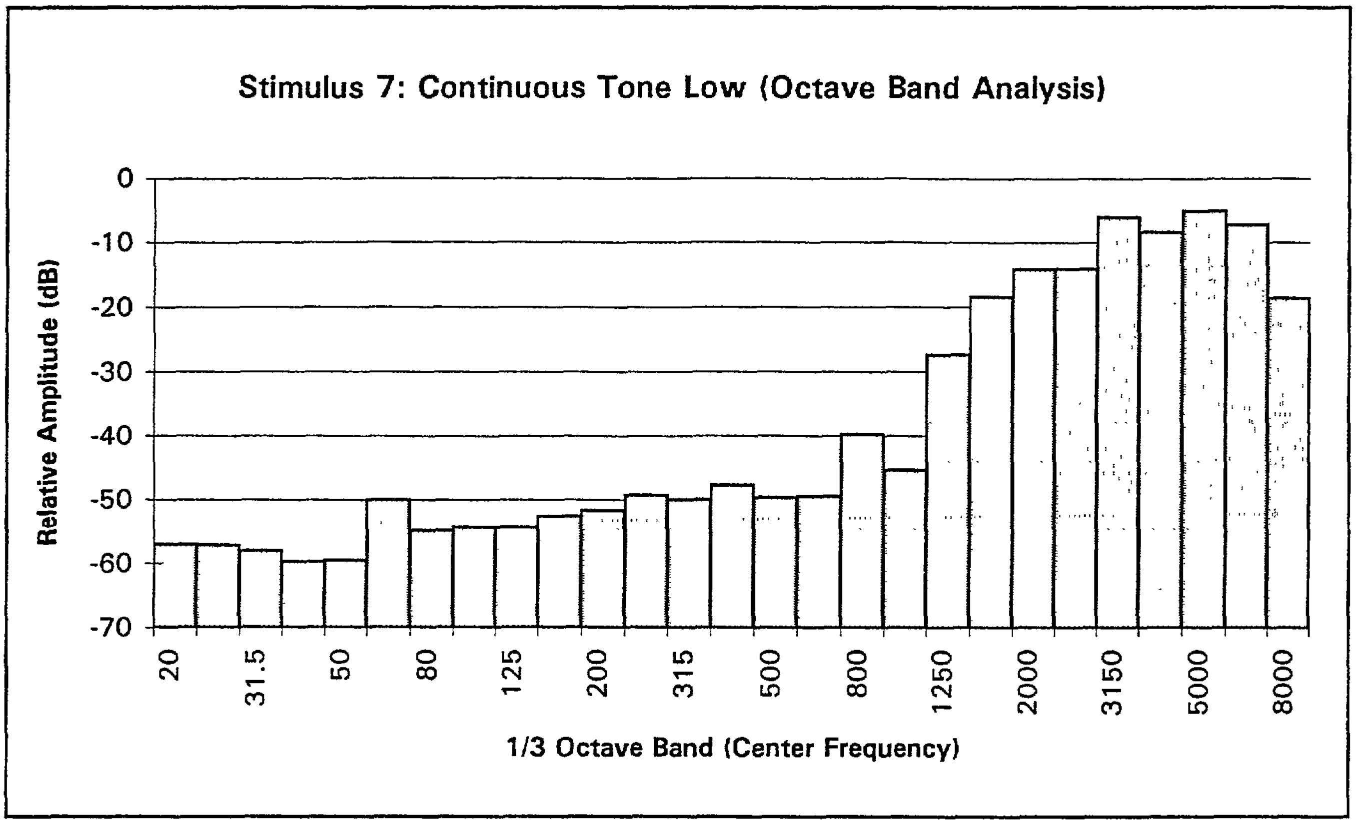


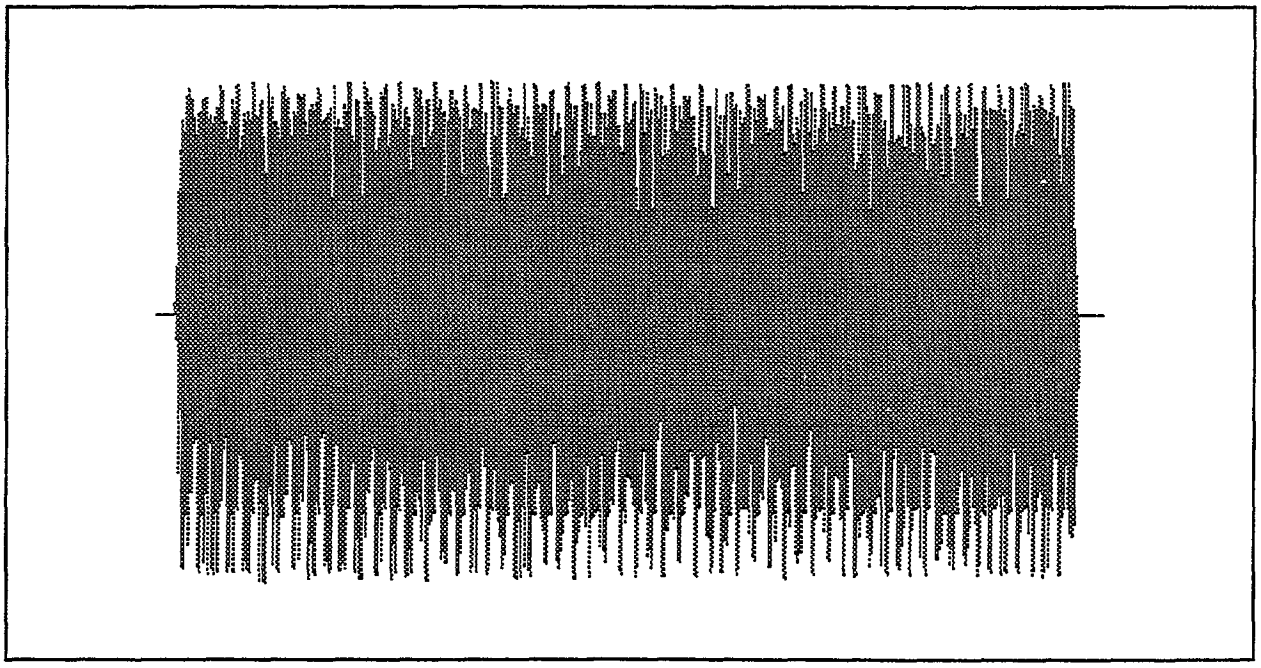
Stimulus 5


Stimulus 6: Continuous Tone High (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)

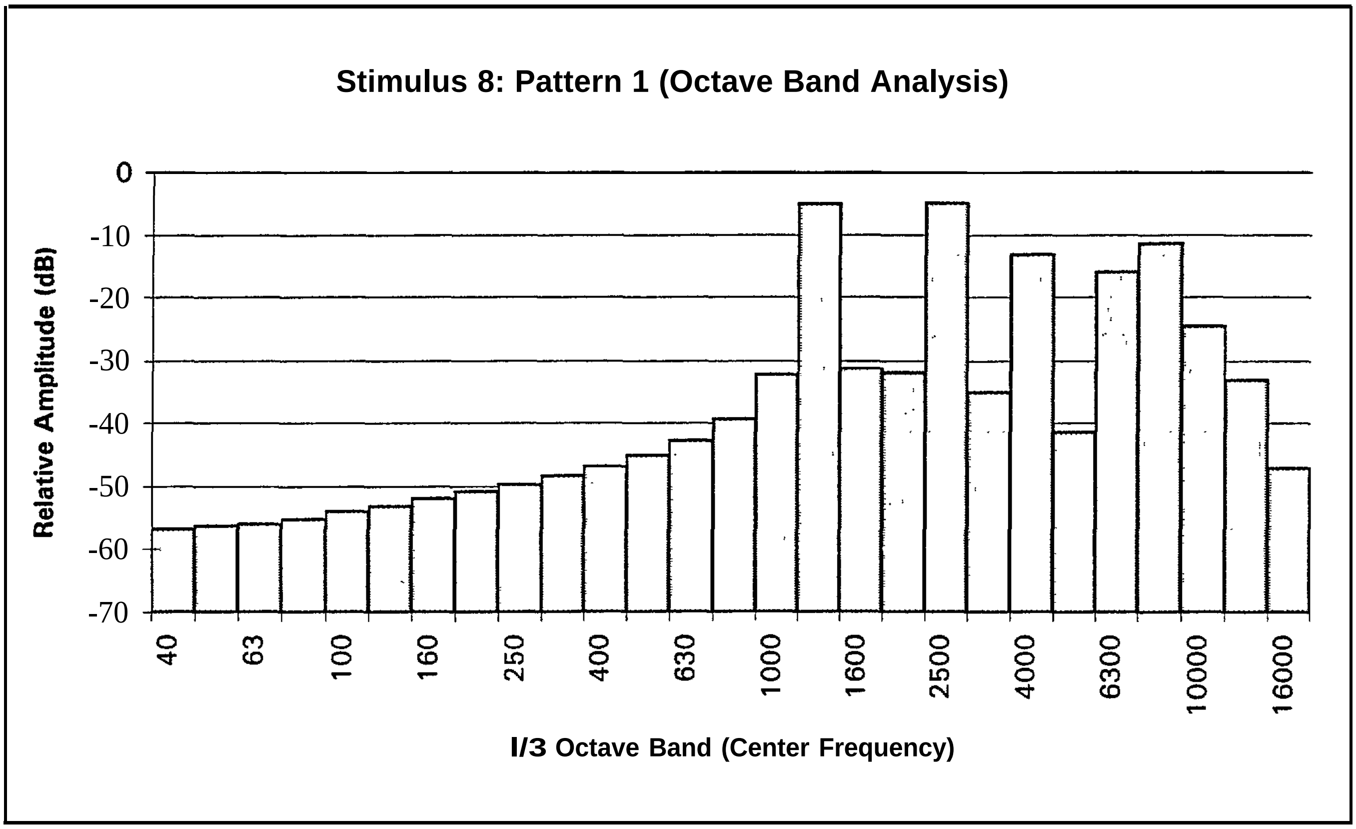


Stimulus 6

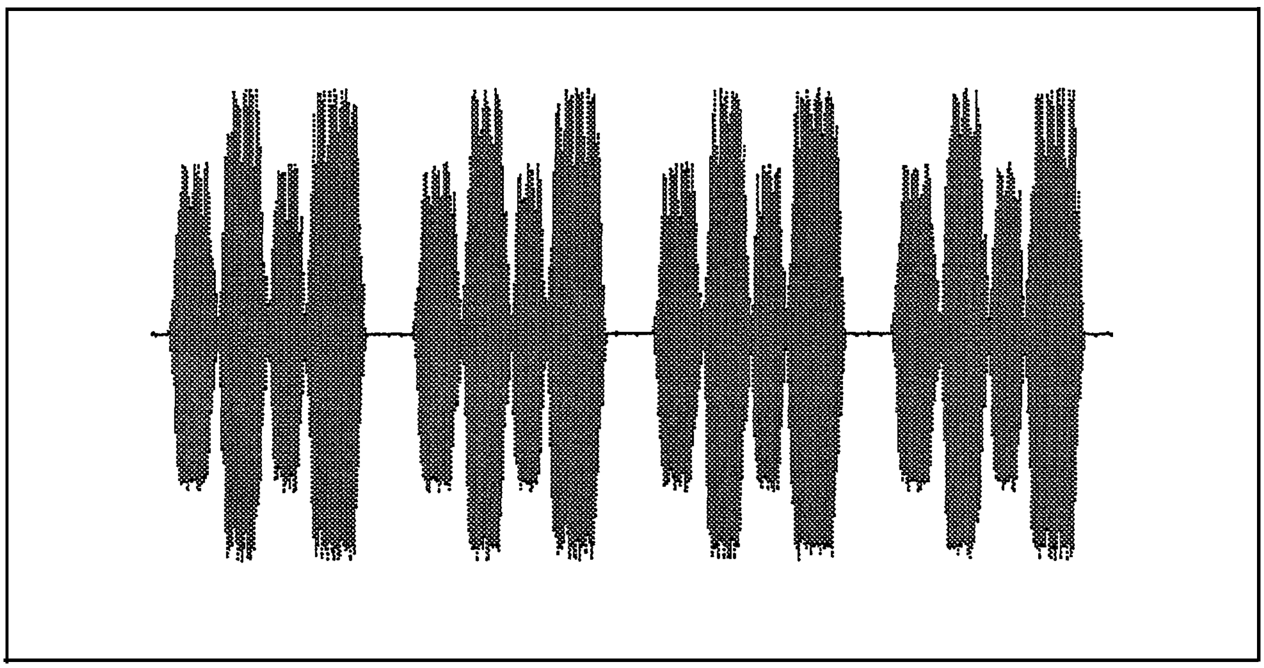

Stimulus 7: Continuous Tone Low (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)



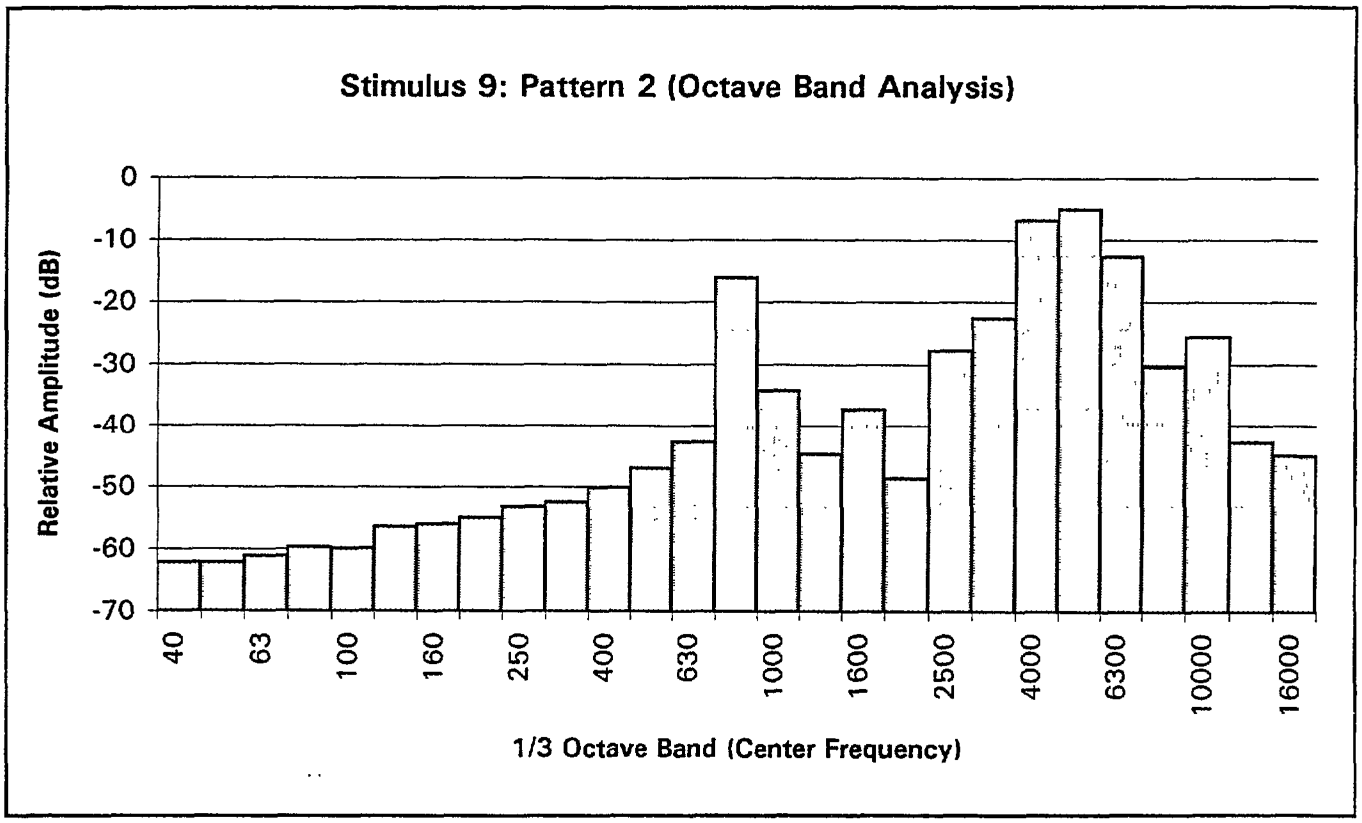
Stimulus 7



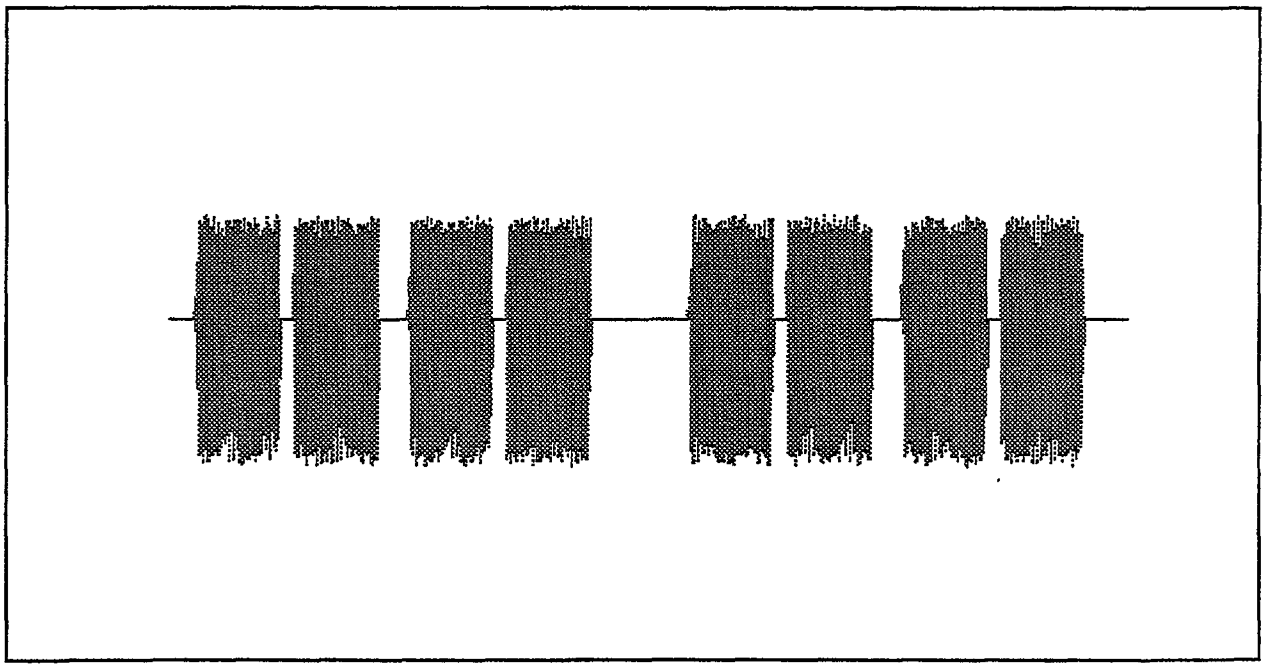
Stimulus 8: Pattern 1 (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
I/3 Octave Band (Center Frequency)



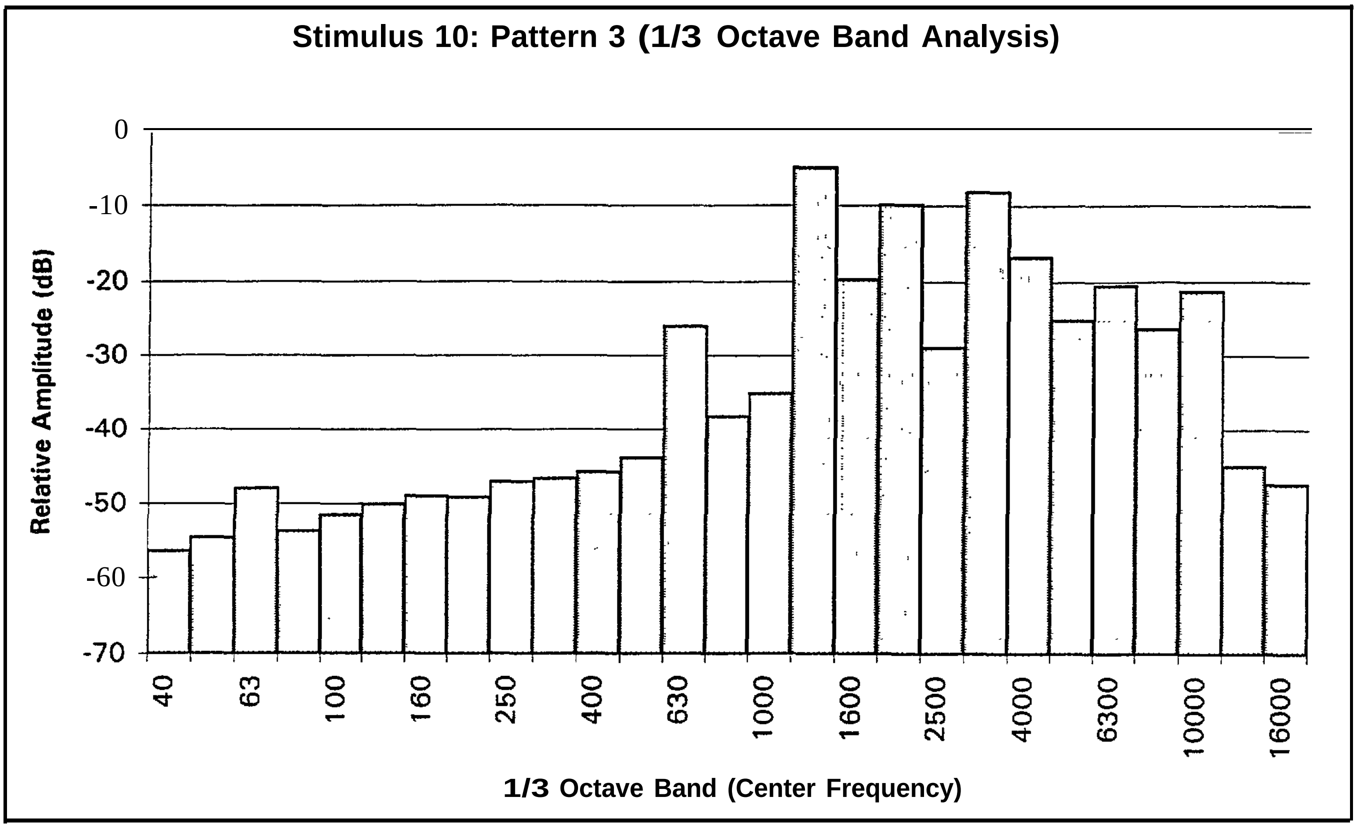
Stimulus 8

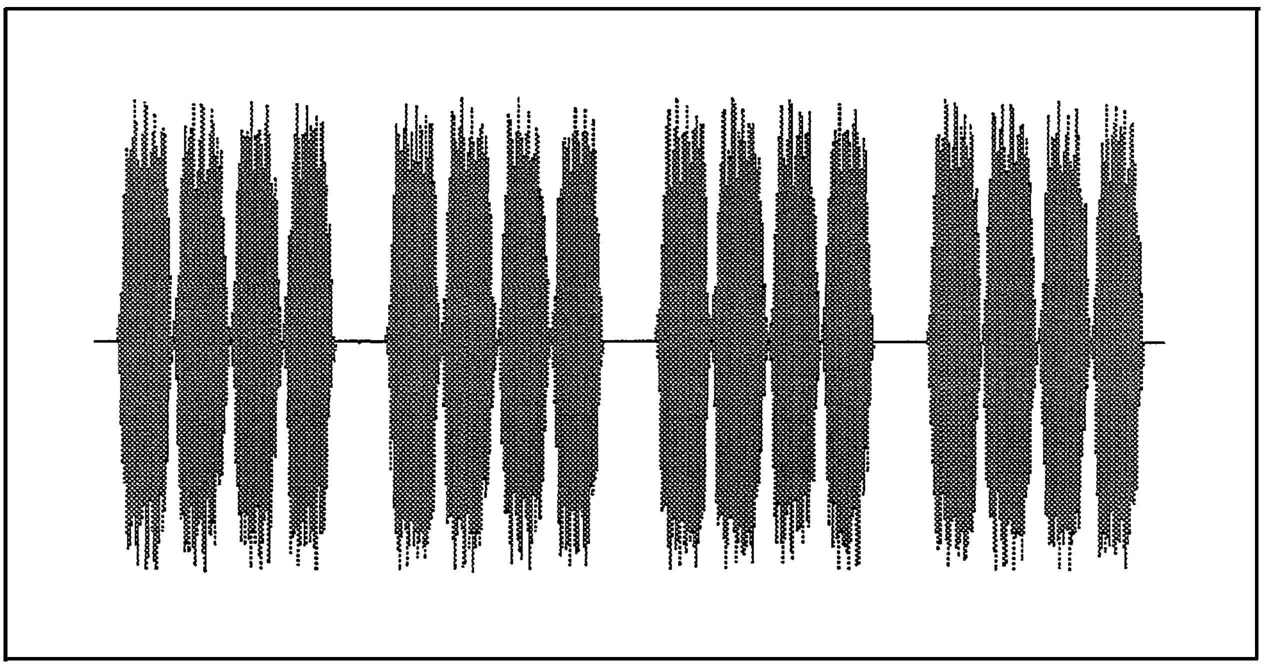


Stimulus 9: Pattern 2 (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)

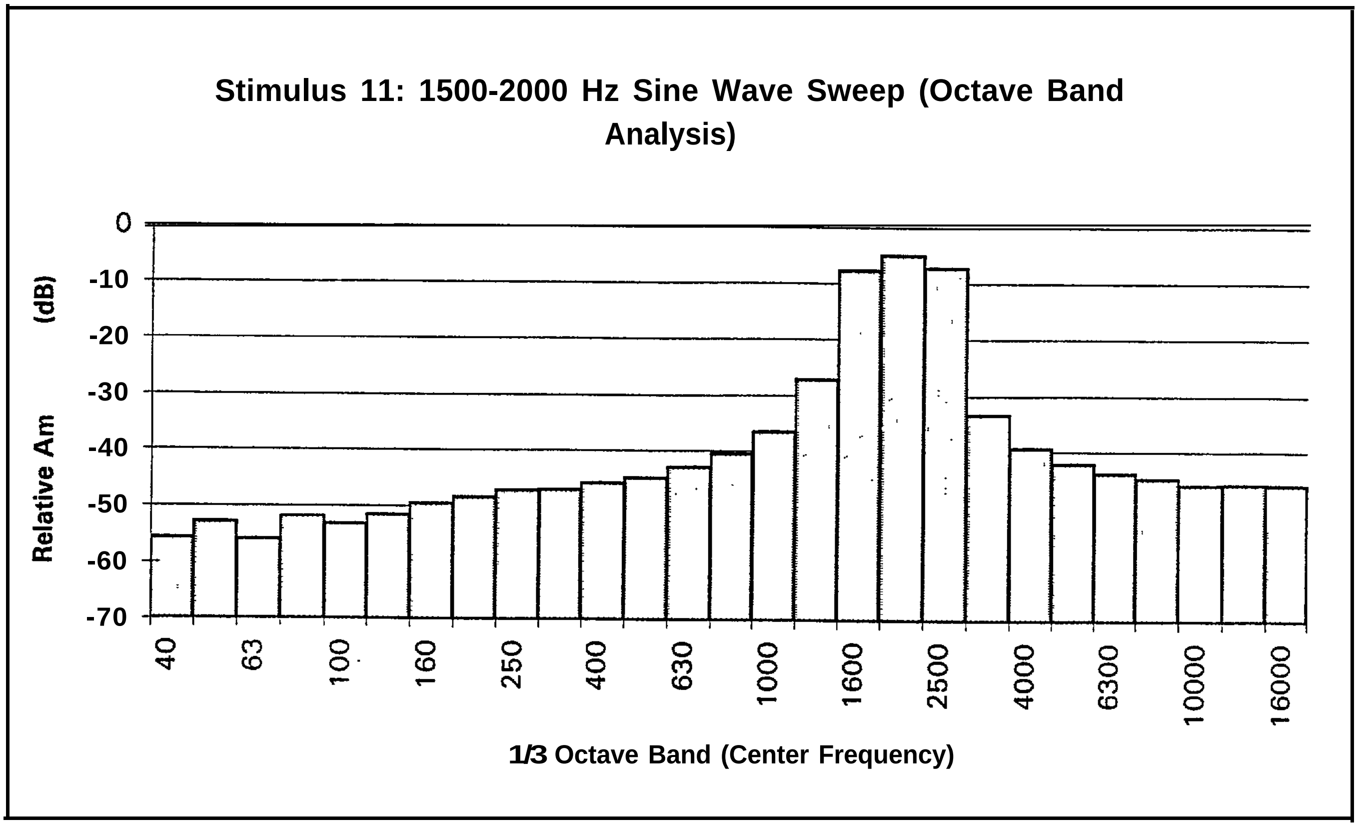


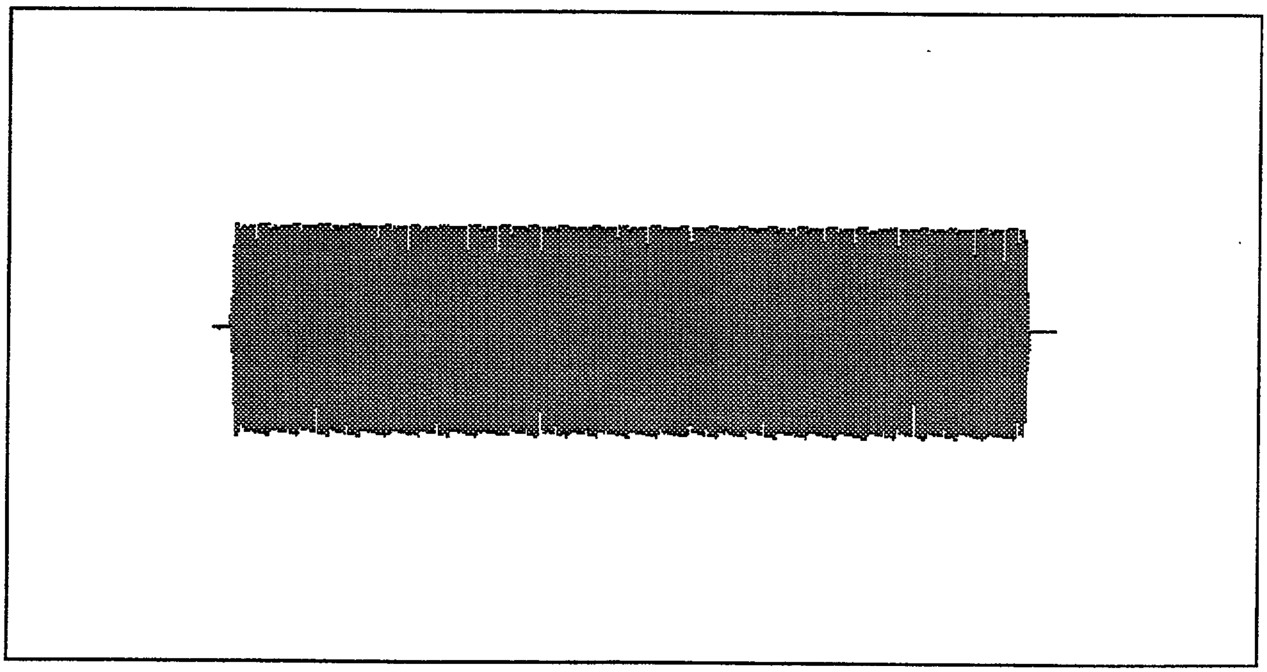
Stimulus 9


Stimulus 10: Pattern 3 (1/3 Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)

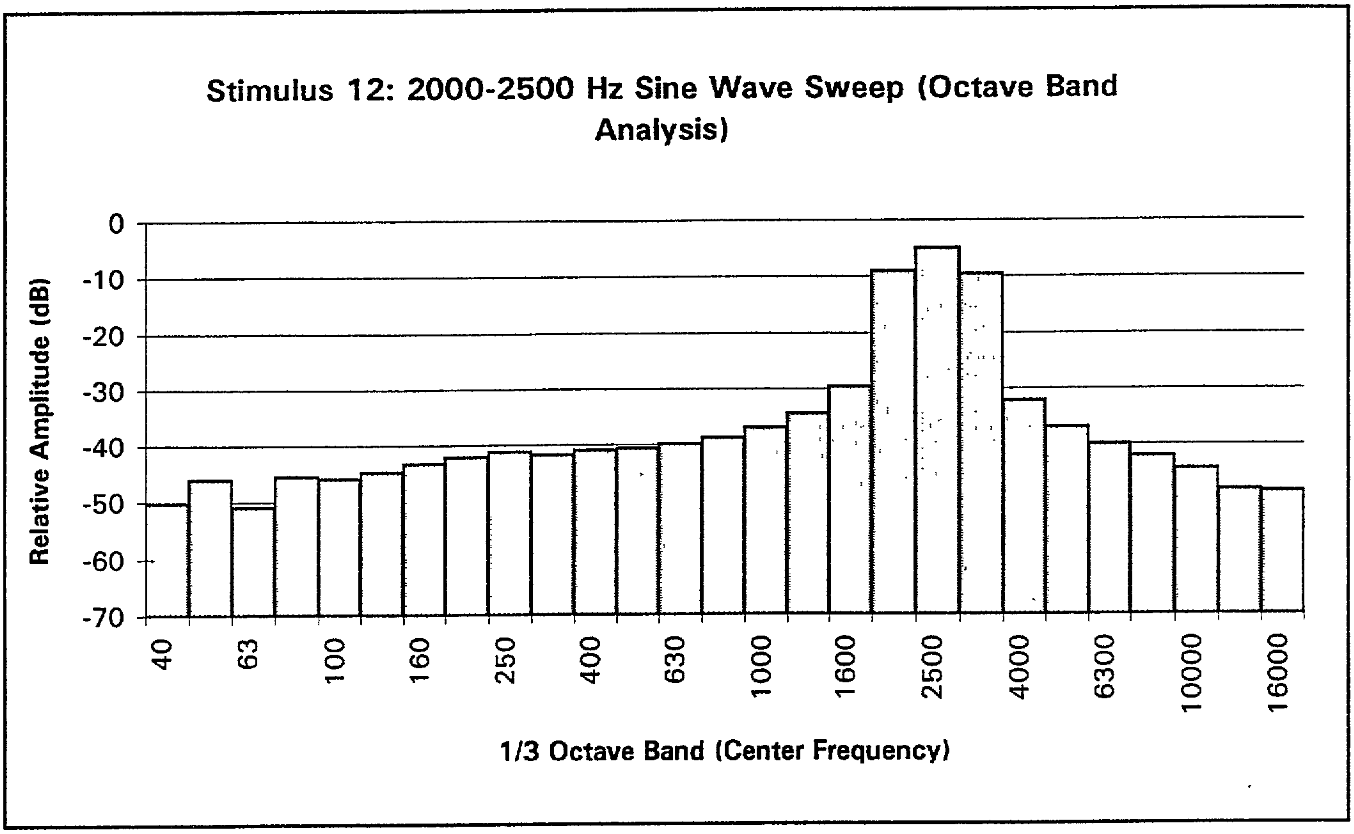


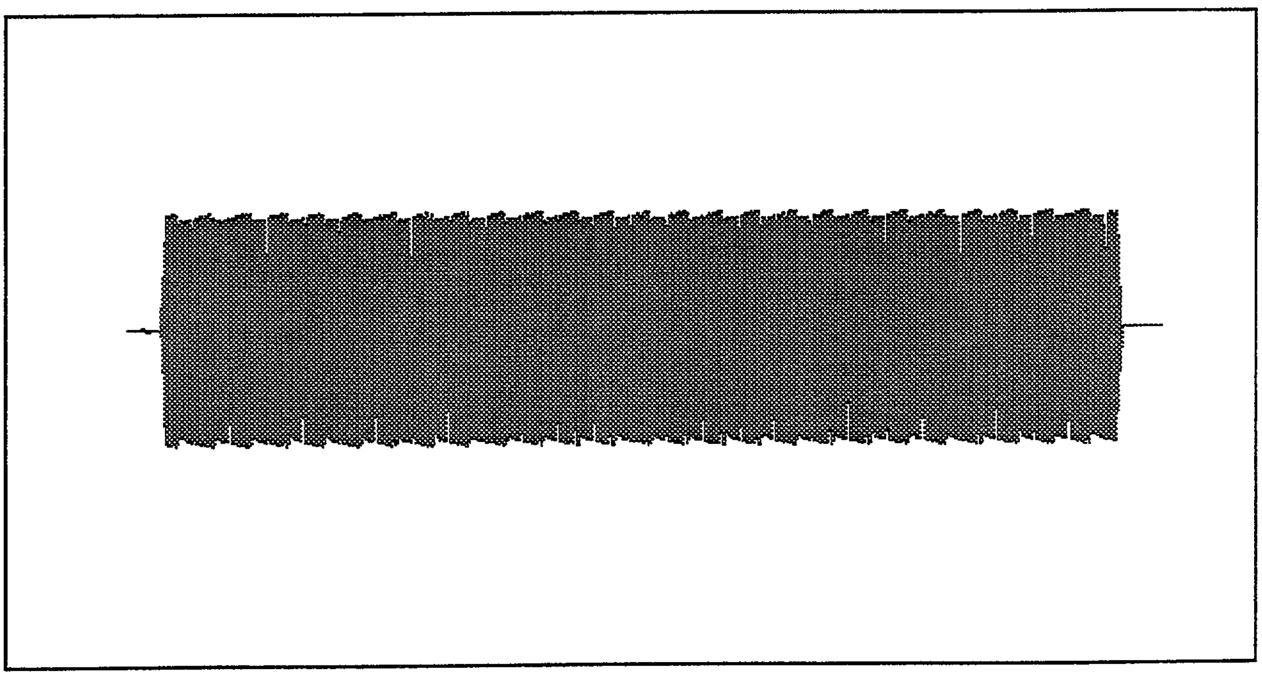
Stimulus 10


Stimulus 11: 1500-2000 Hz Sine Wave Sweep (Octave Band Analysis)
Relative Am (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)

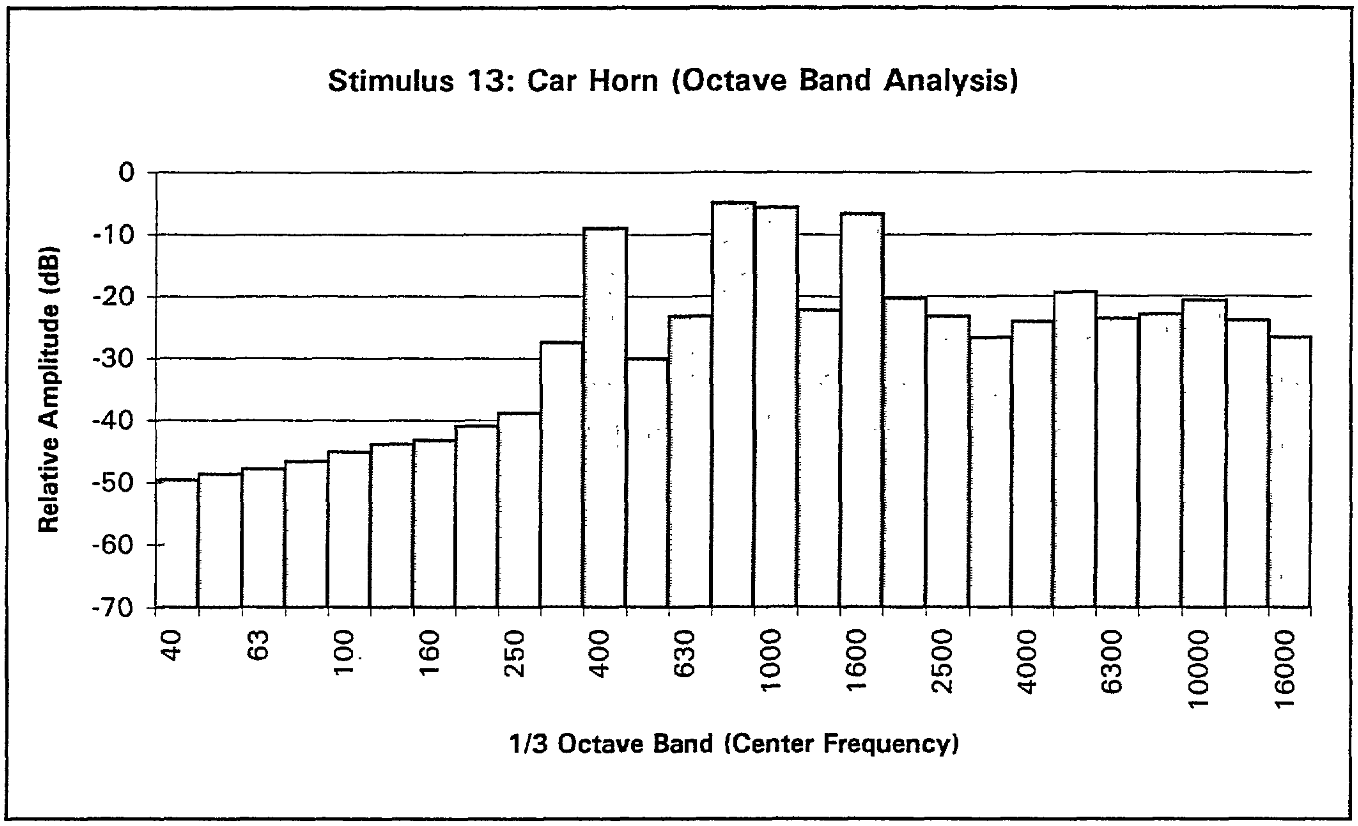


Stimulus 14

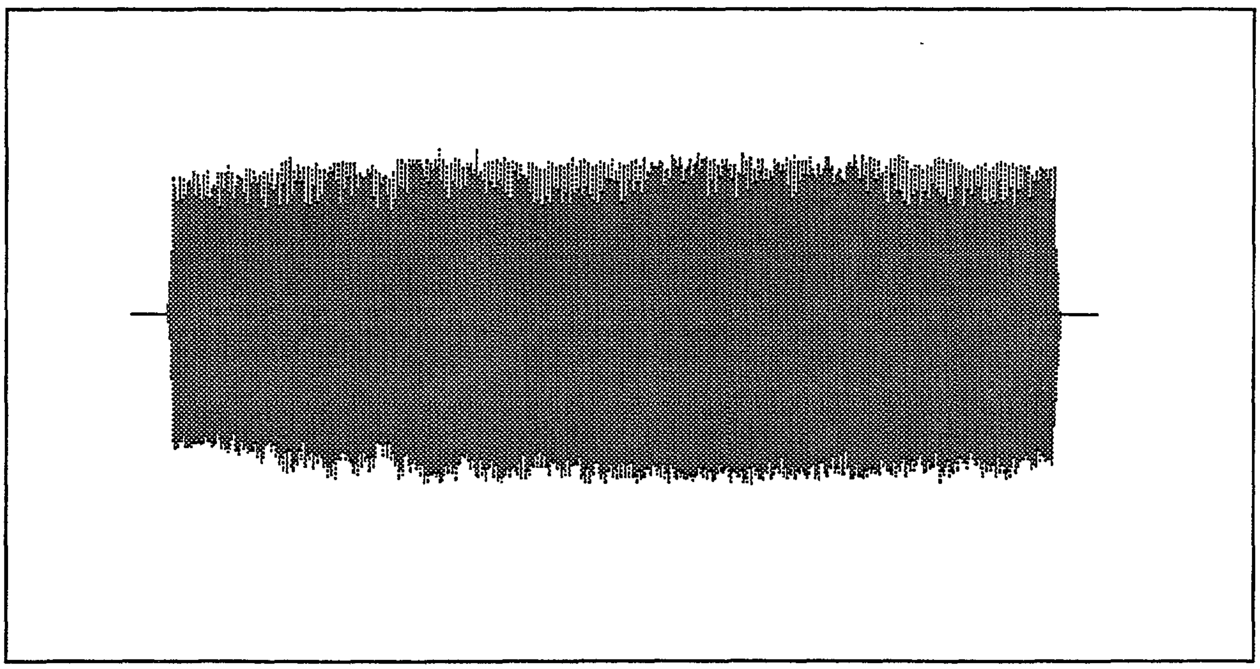

Stimulus 12: 2000-2500 Hz Sine Wave Sweep (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)



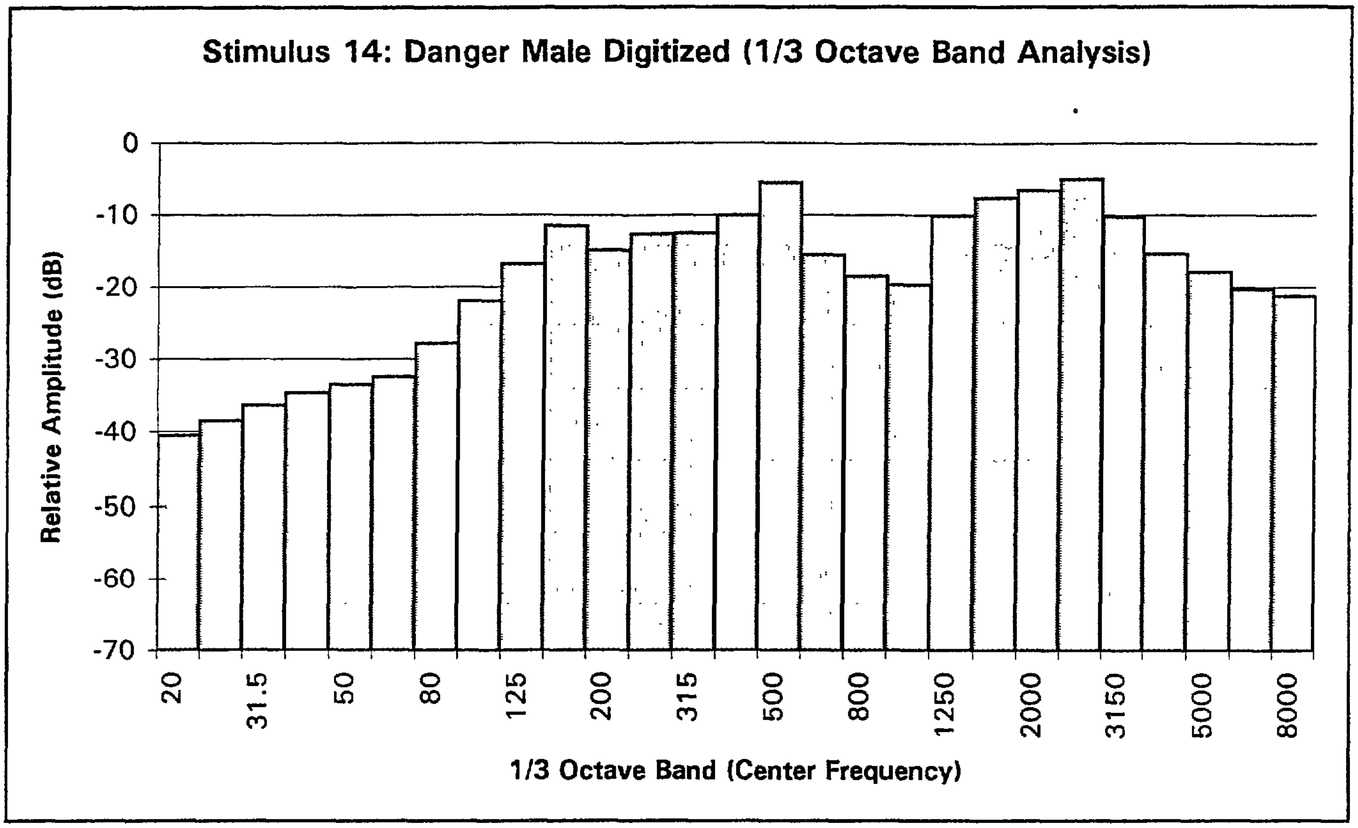
Stimulus 12



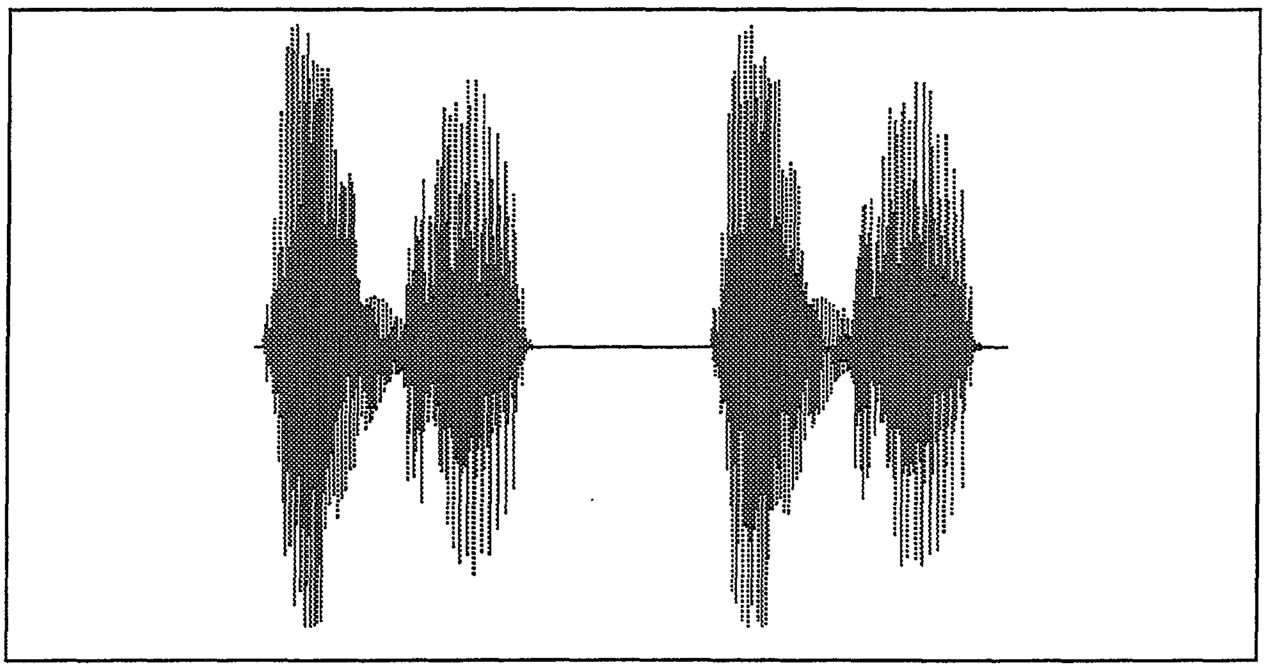
Stimulus 13: Car Horn (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency)



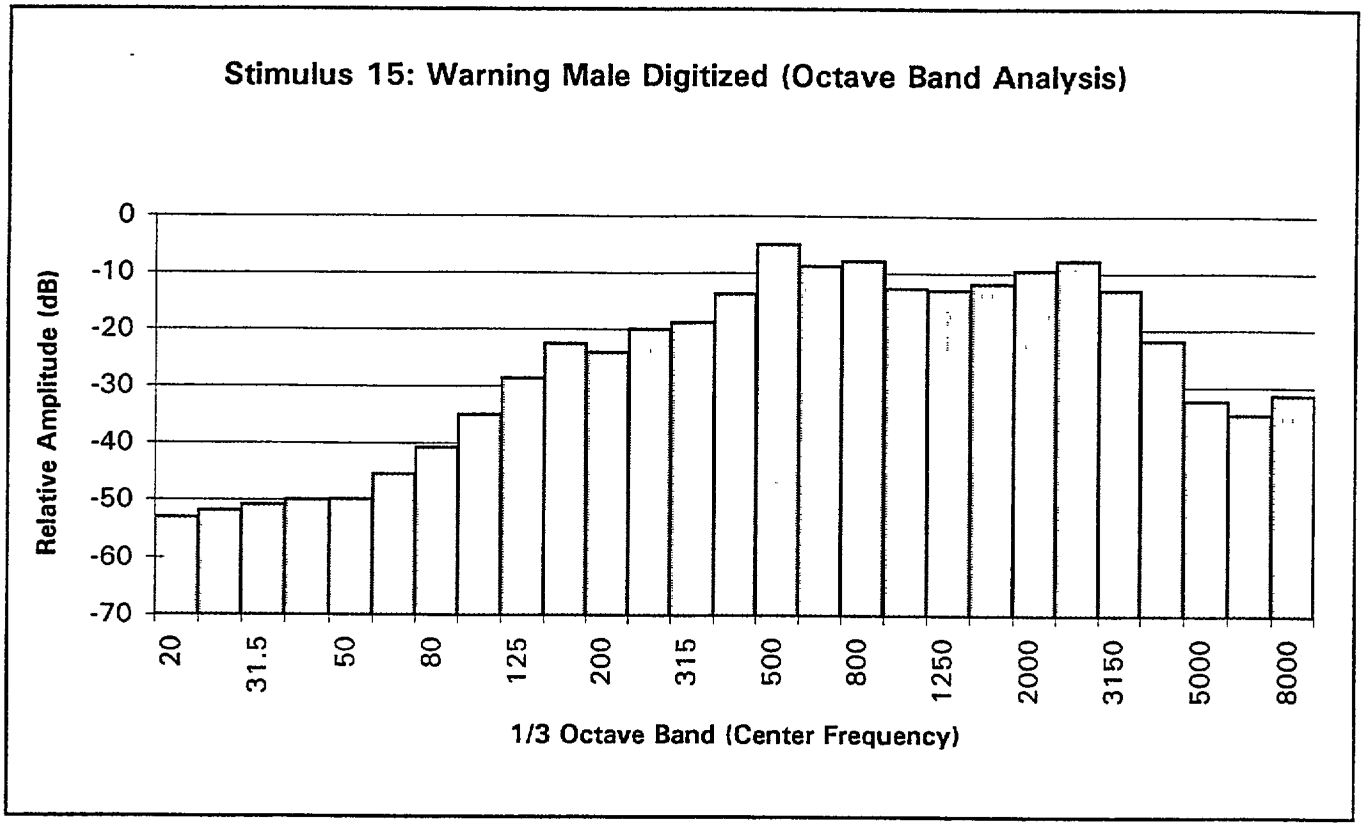
Stimulus 13

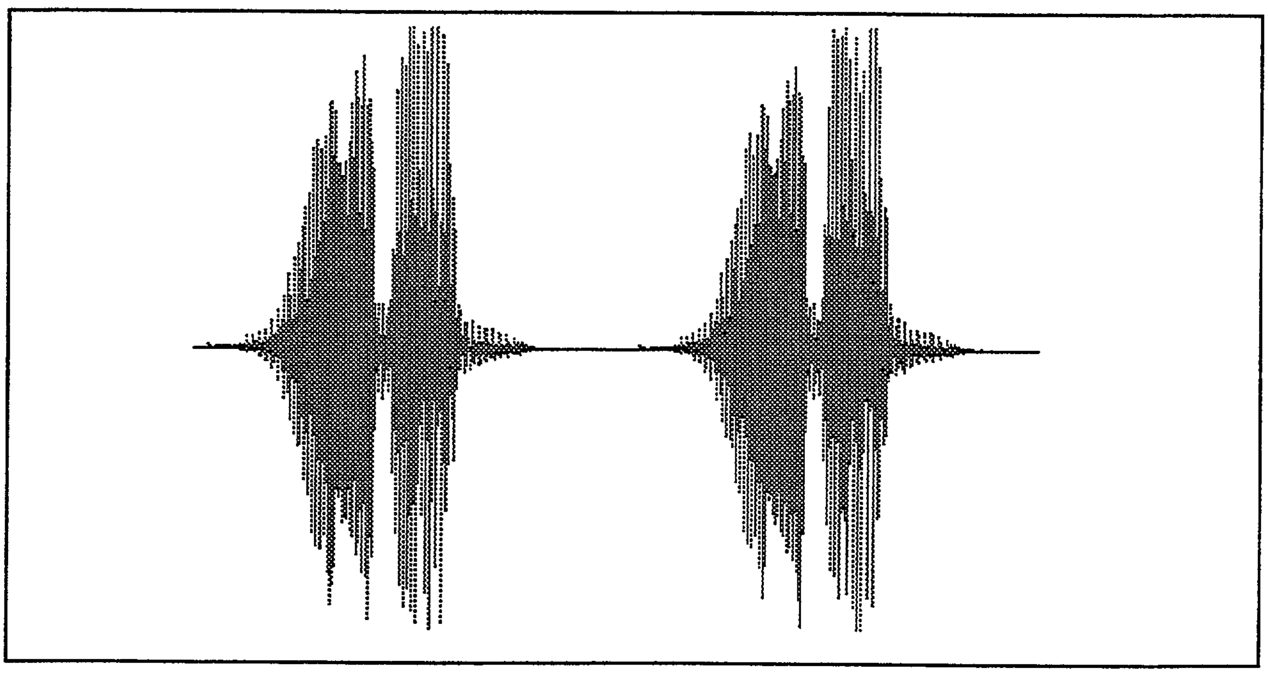


Stimulus 14: Danger Male Digitized (1/3 Octave Band Analysis)
0
-10
-20
-30
-40
-50
-60
-70
Relative Amplitude (dB)
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)

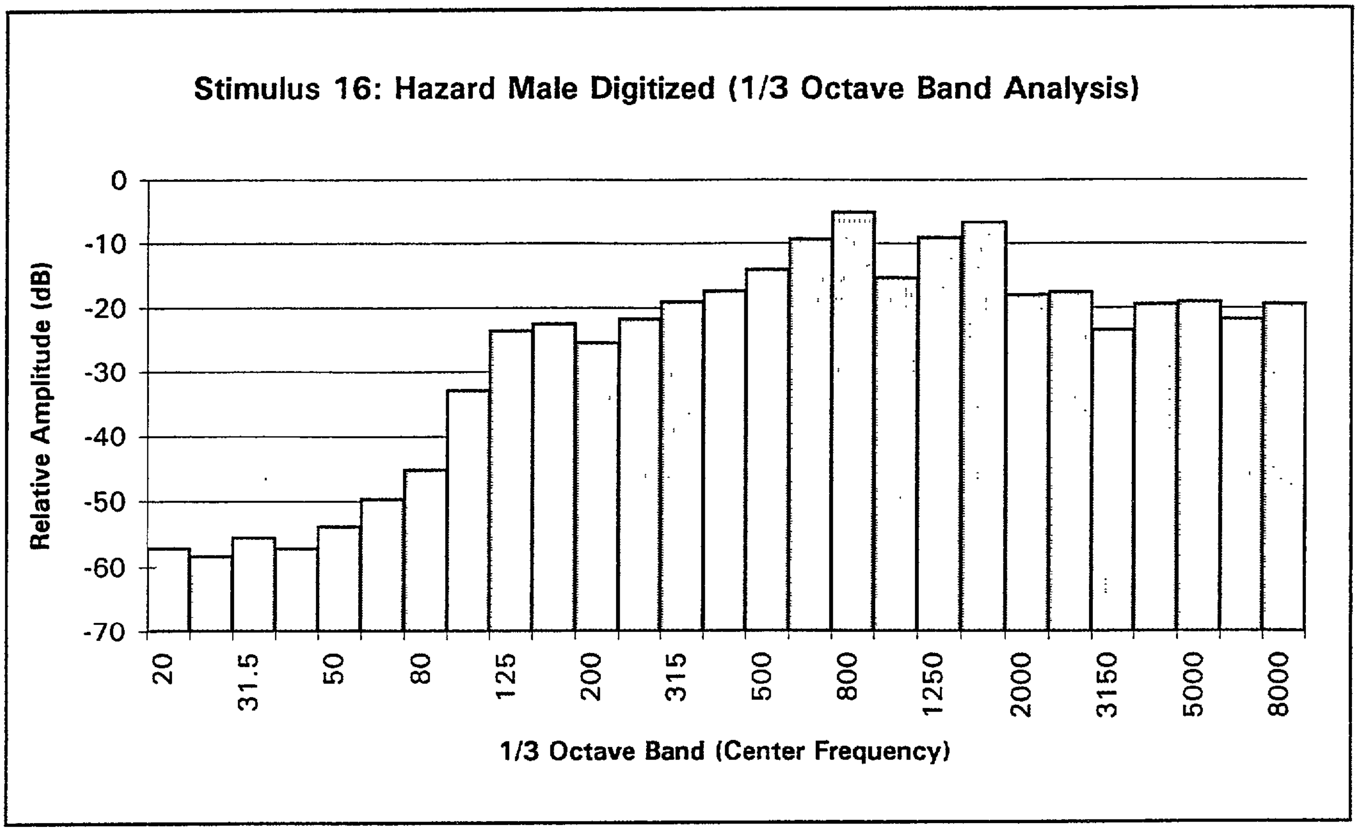


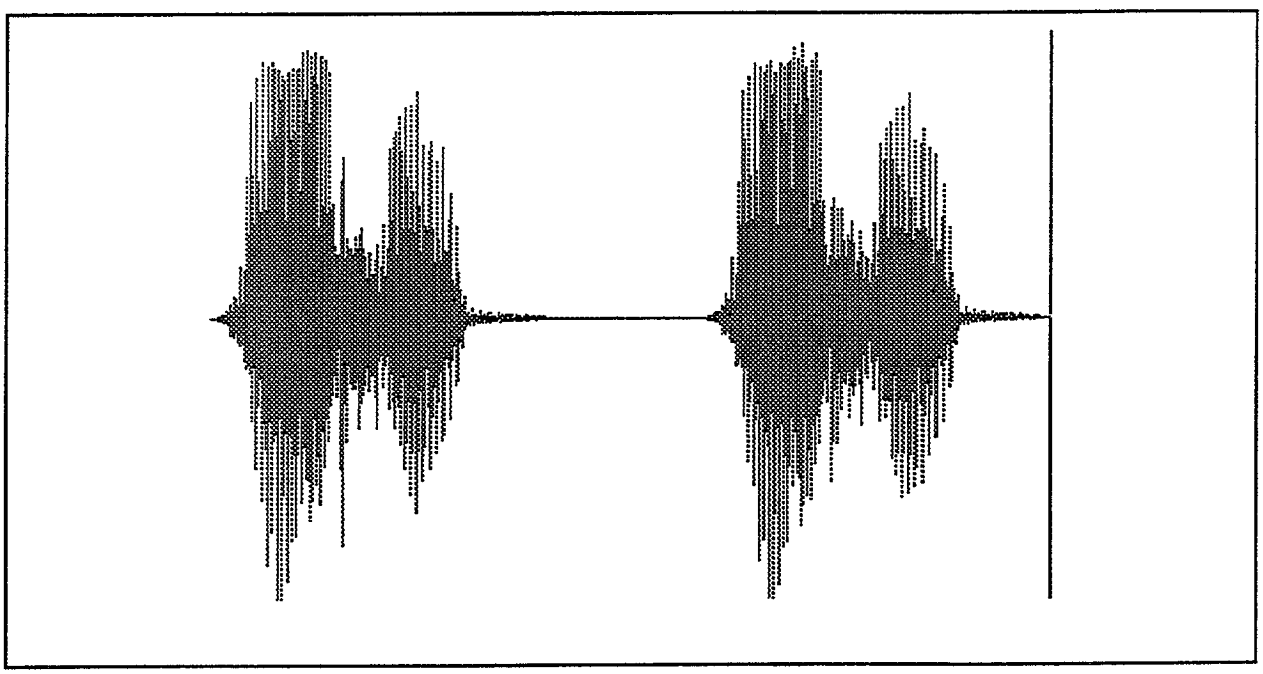
Stimulus 14


Stimulus 15: Warning Male Digitized (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)

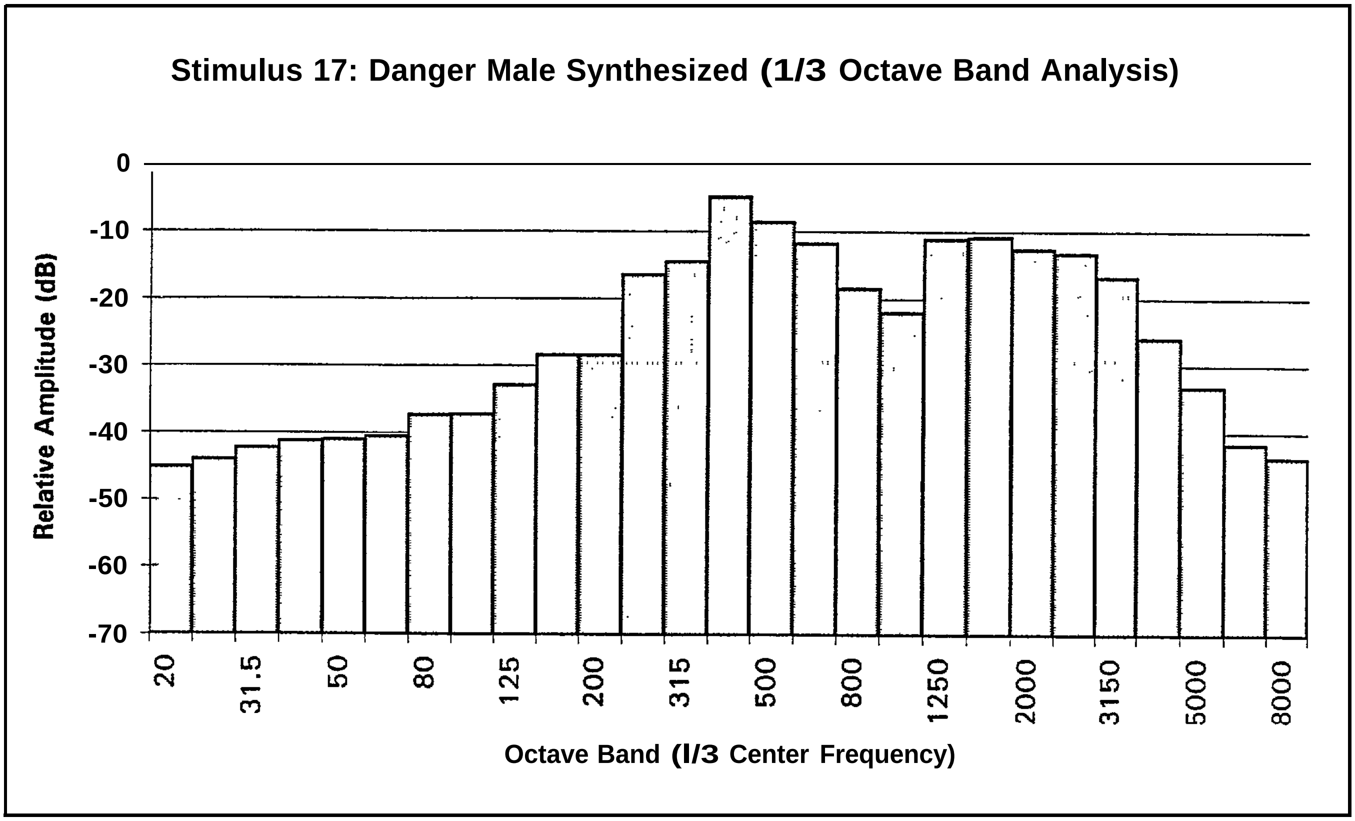


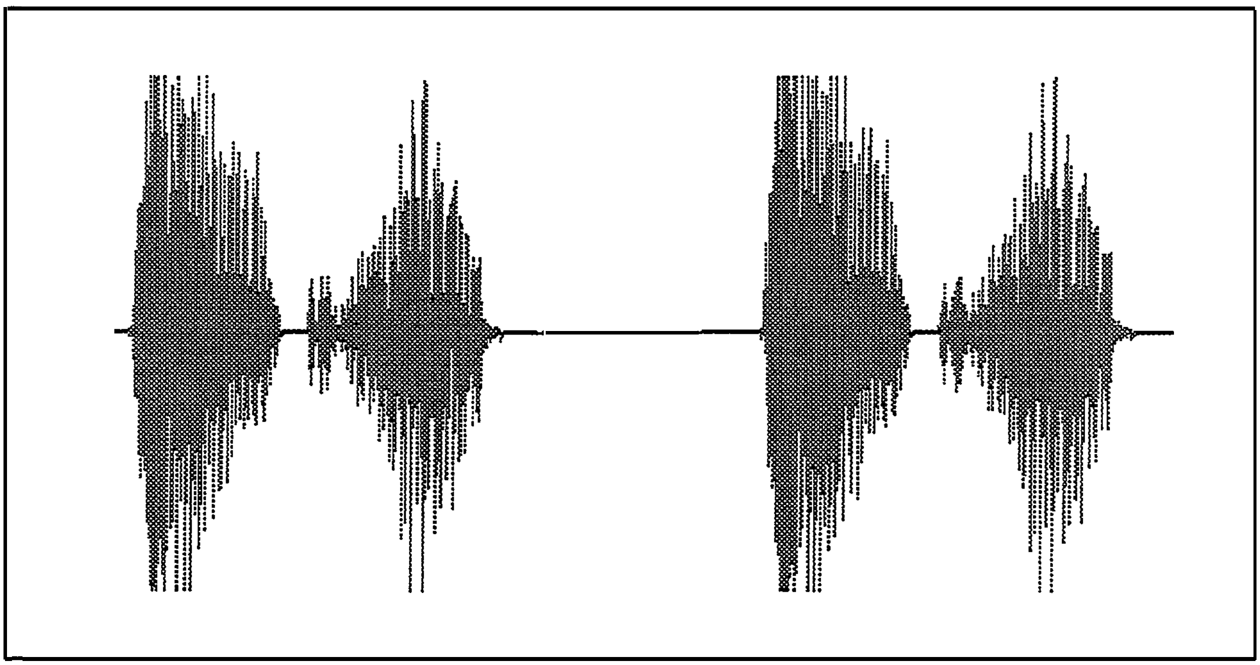
Stimulus 15


Stimulus 16: Hazard Male Digitized (1/3 Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)

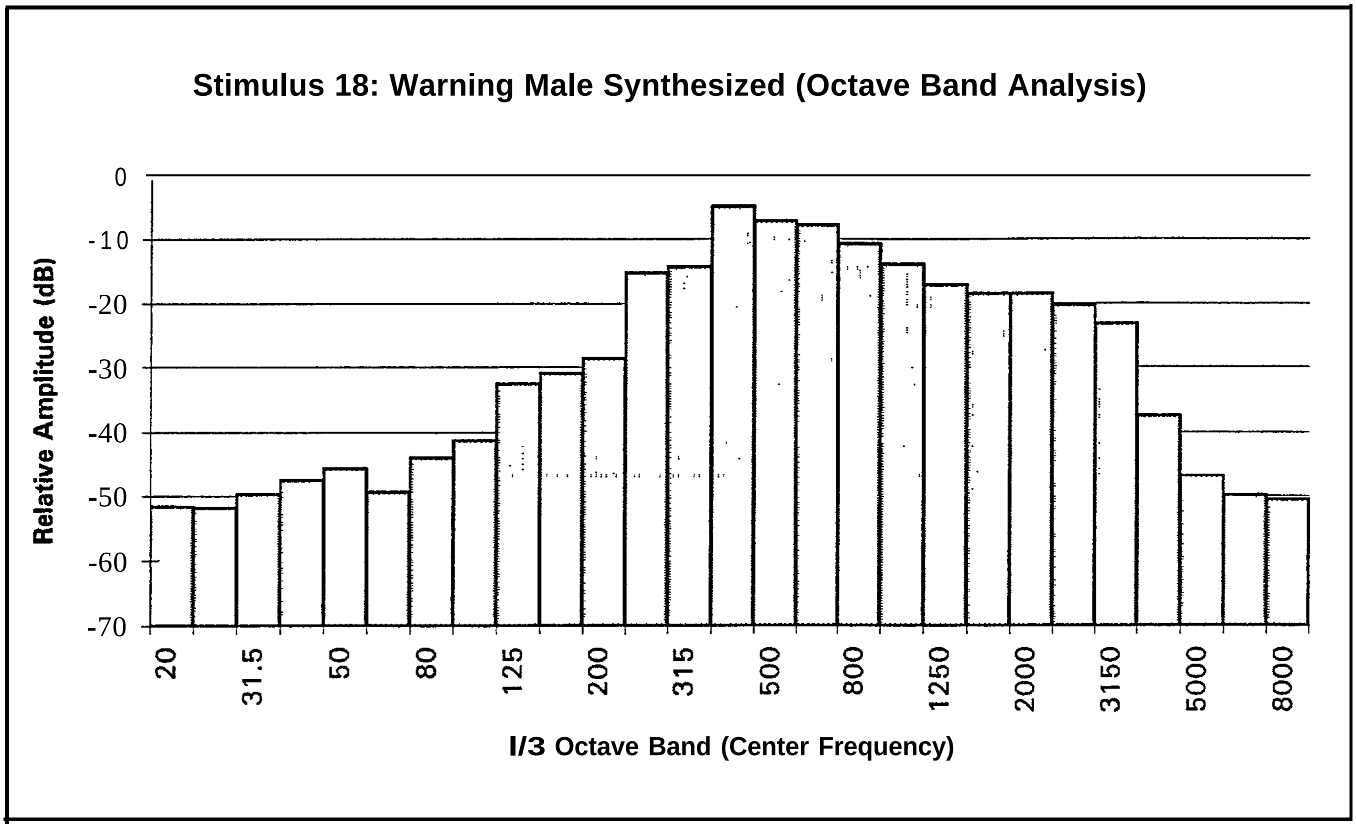


Stimulus 16

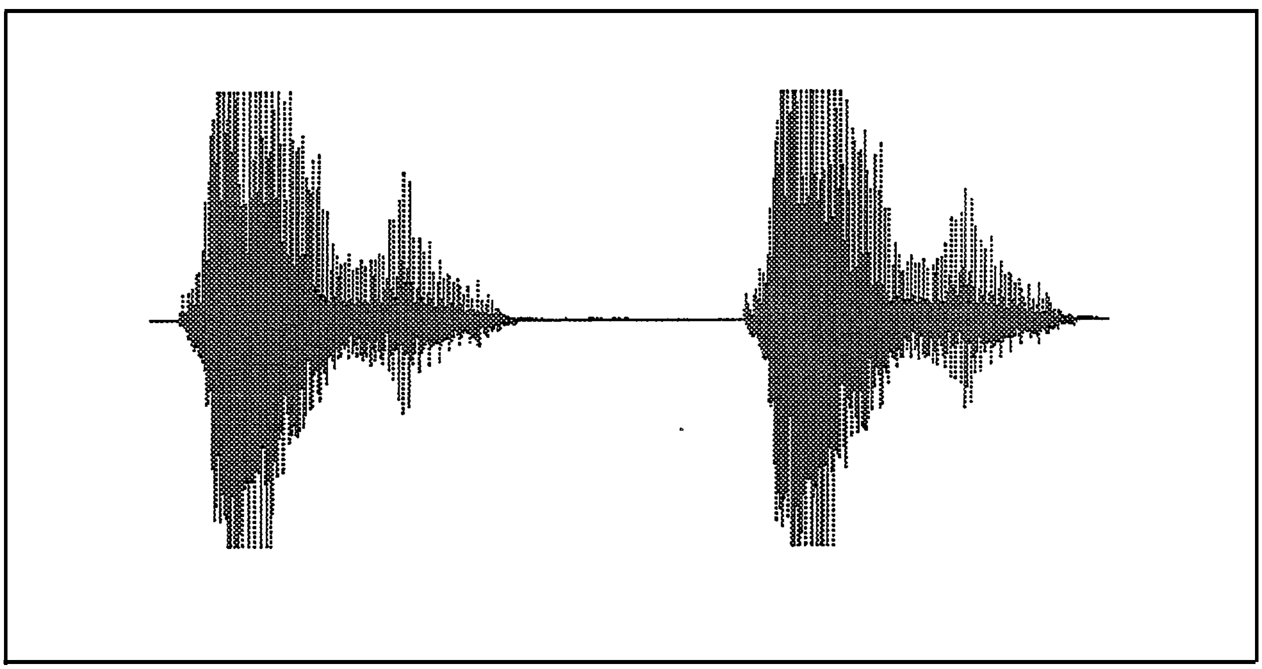

Stimulus 17: Danger Male Synthesized (1/3 Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
Octave Band (l/3 Center Frequency)



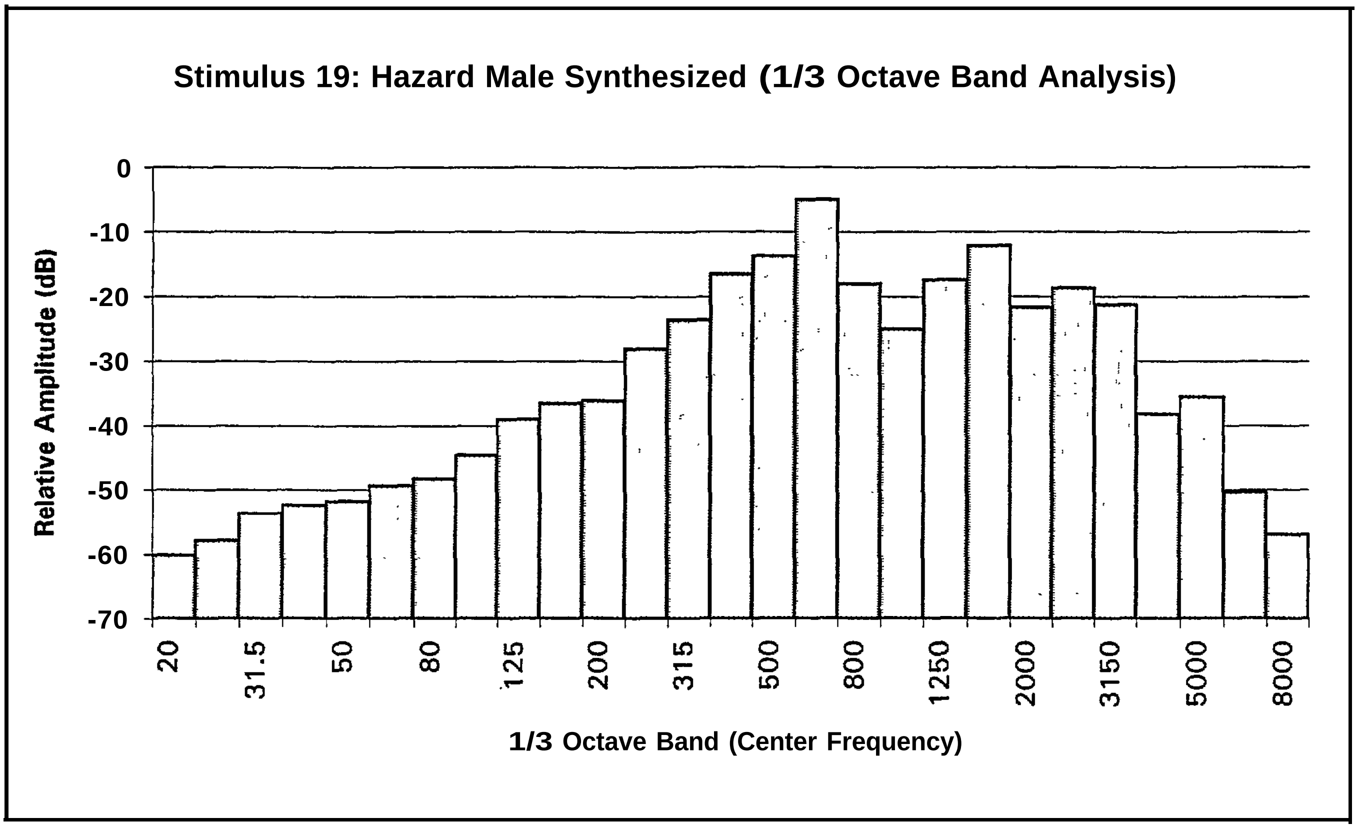
Stimulus 17

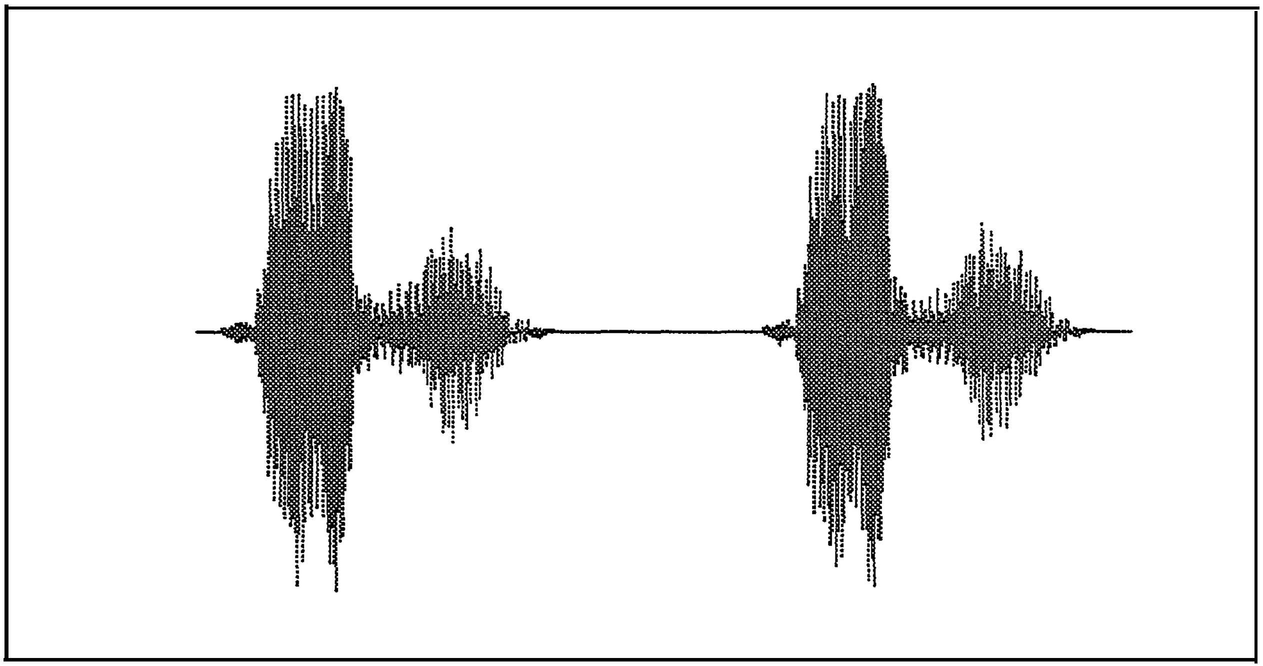


Stimulus 18: Warning Male Synthesized (Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
I/3 Octave Band (Center Frequency)

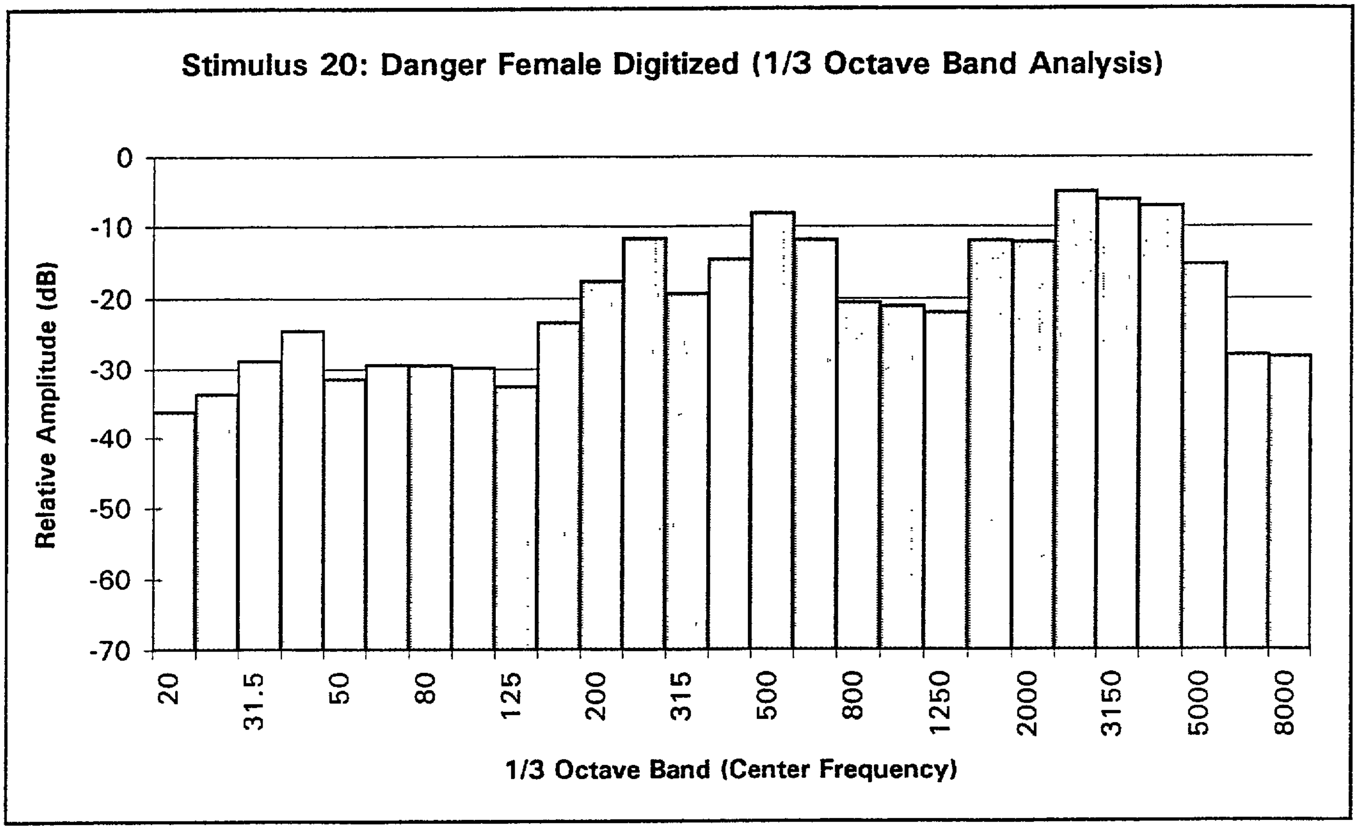


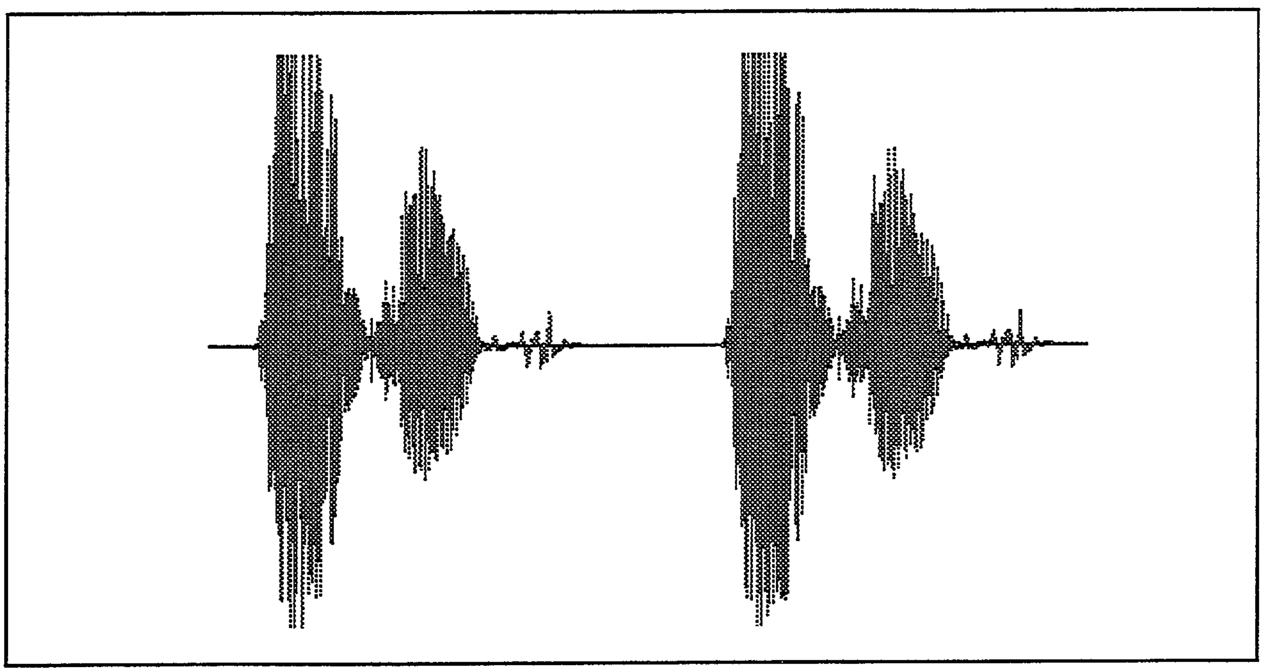
Stimulus 18


Stimulus 19: Hazard Male Synthesized (1/3 Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)

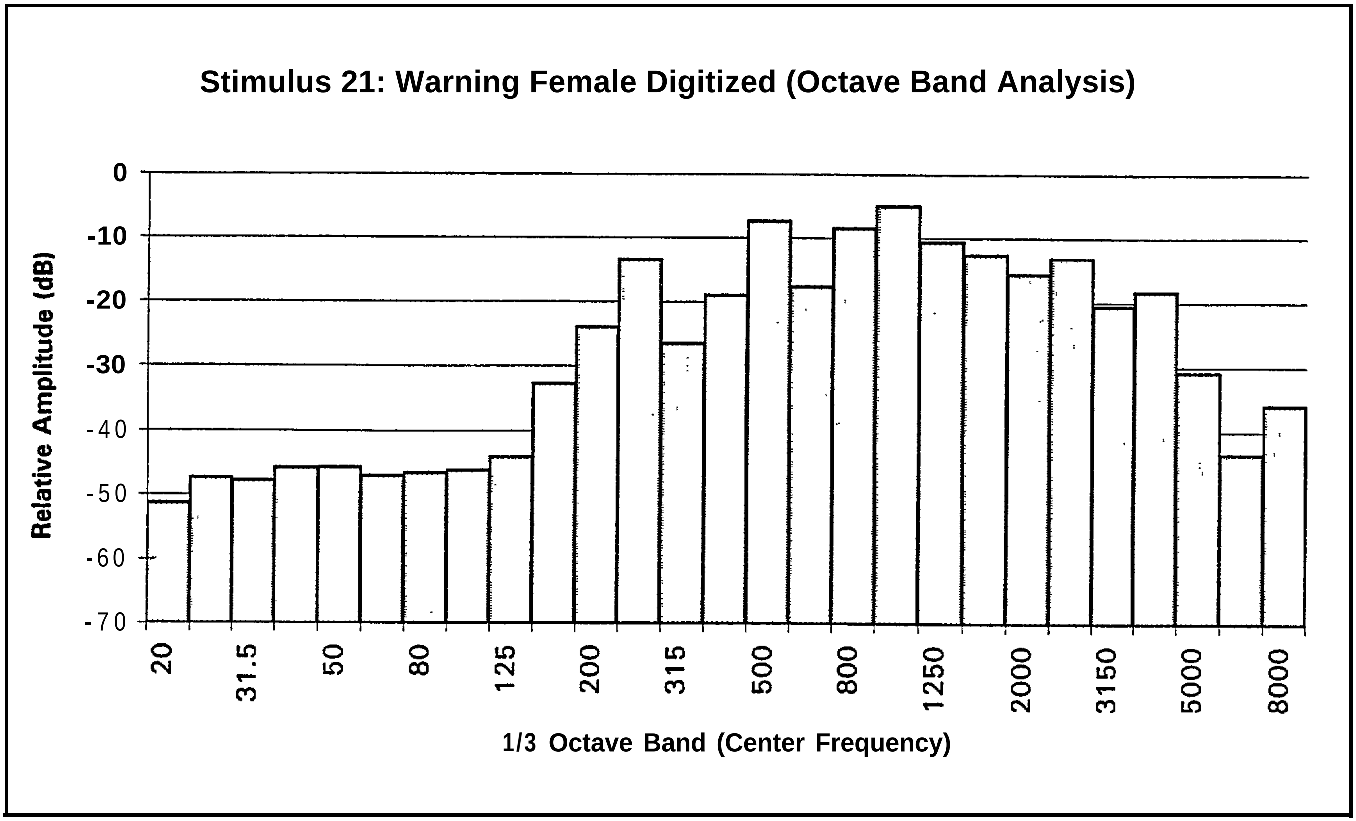


Stimulus 19

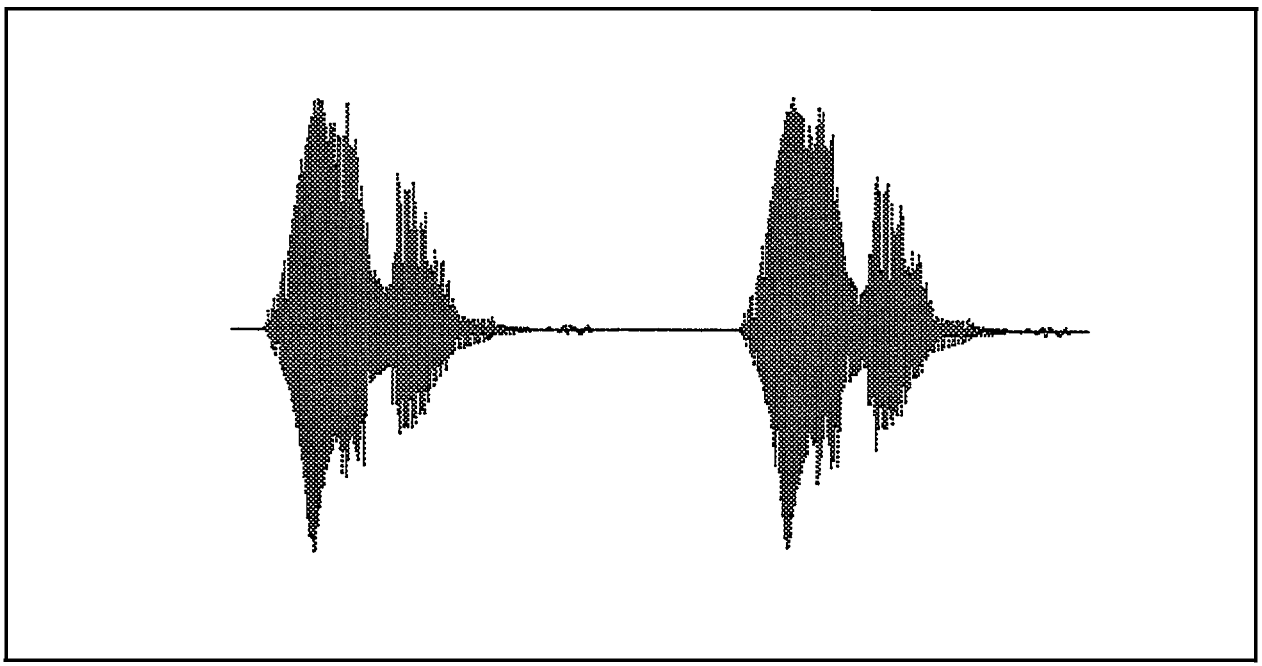

Stimulus 20: Danger Female Digitized (1/3 Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)



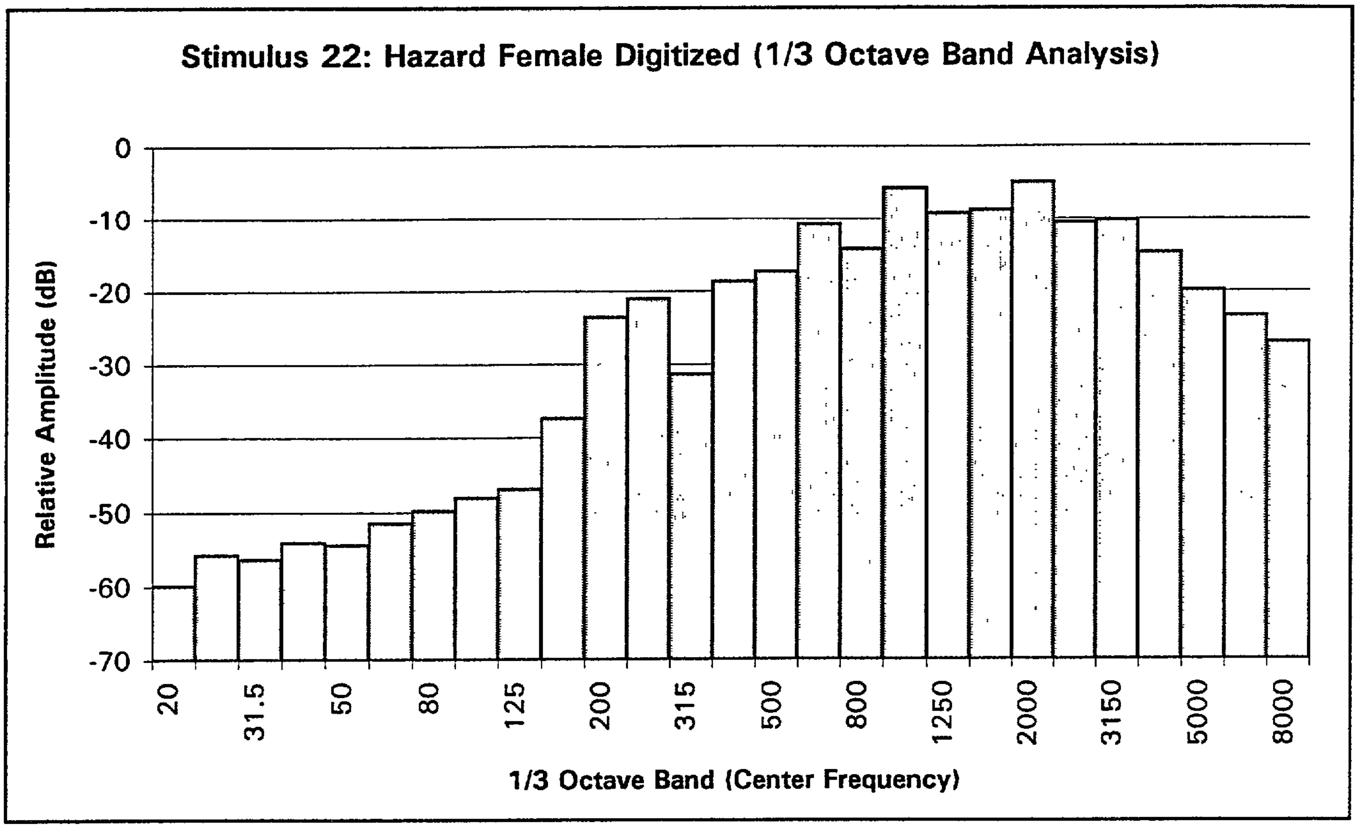
Stimulus 20

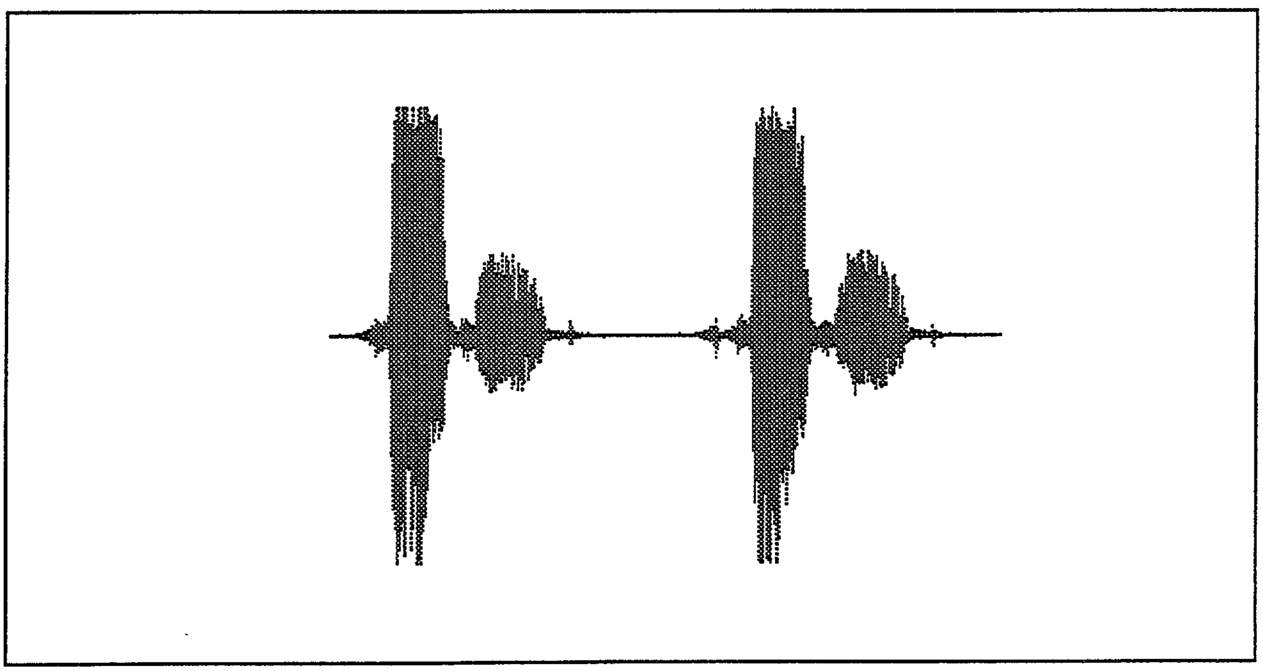


Stimulus 21: Warning Female Digitized (Octave Band Analysis)
0
-10
-20
-30
-40
-50
-60
-70
Relative Amplitude (dB)
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)

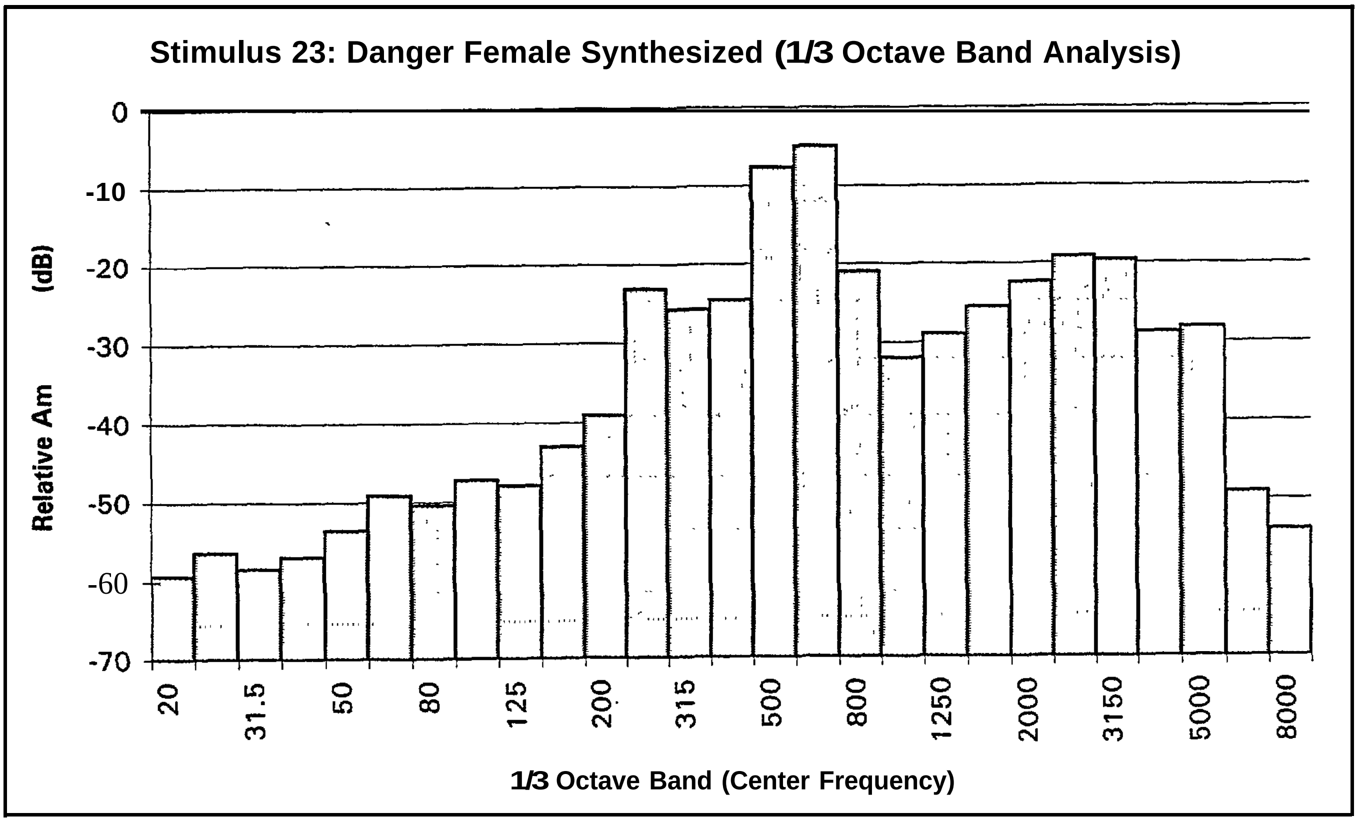


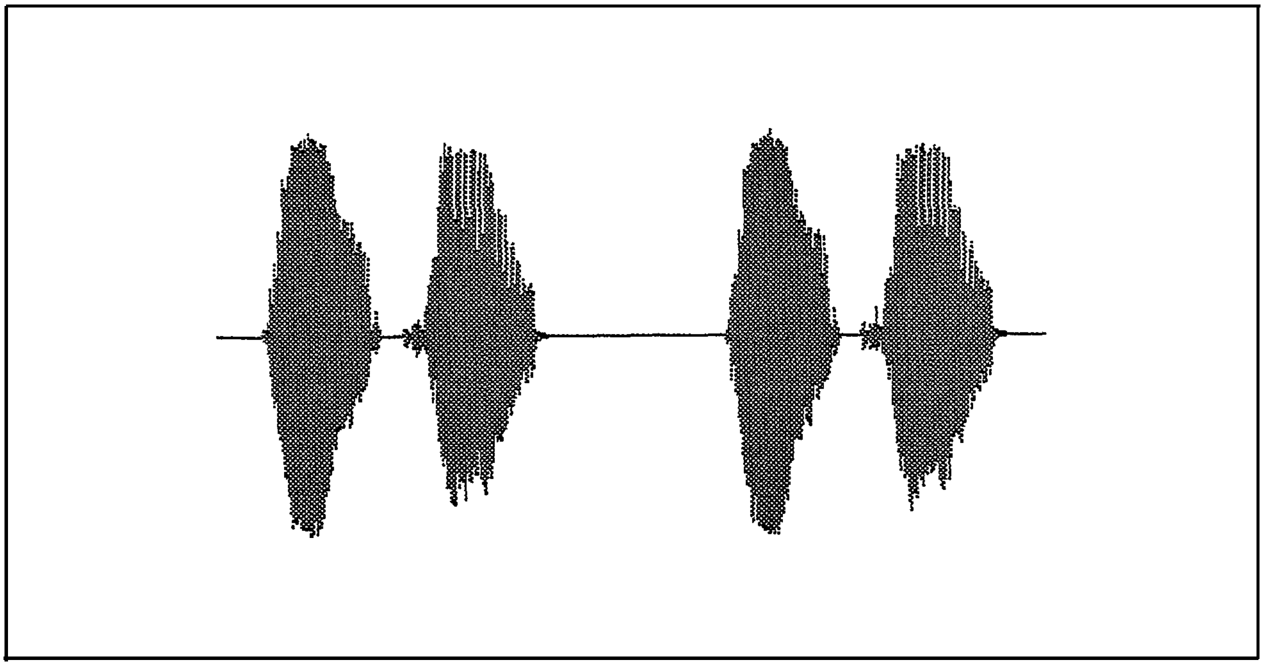
Stimulus 21


Stimulus 22: Hazard Female Digitized (1/3 Octave Band Analysis)
Relative Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)

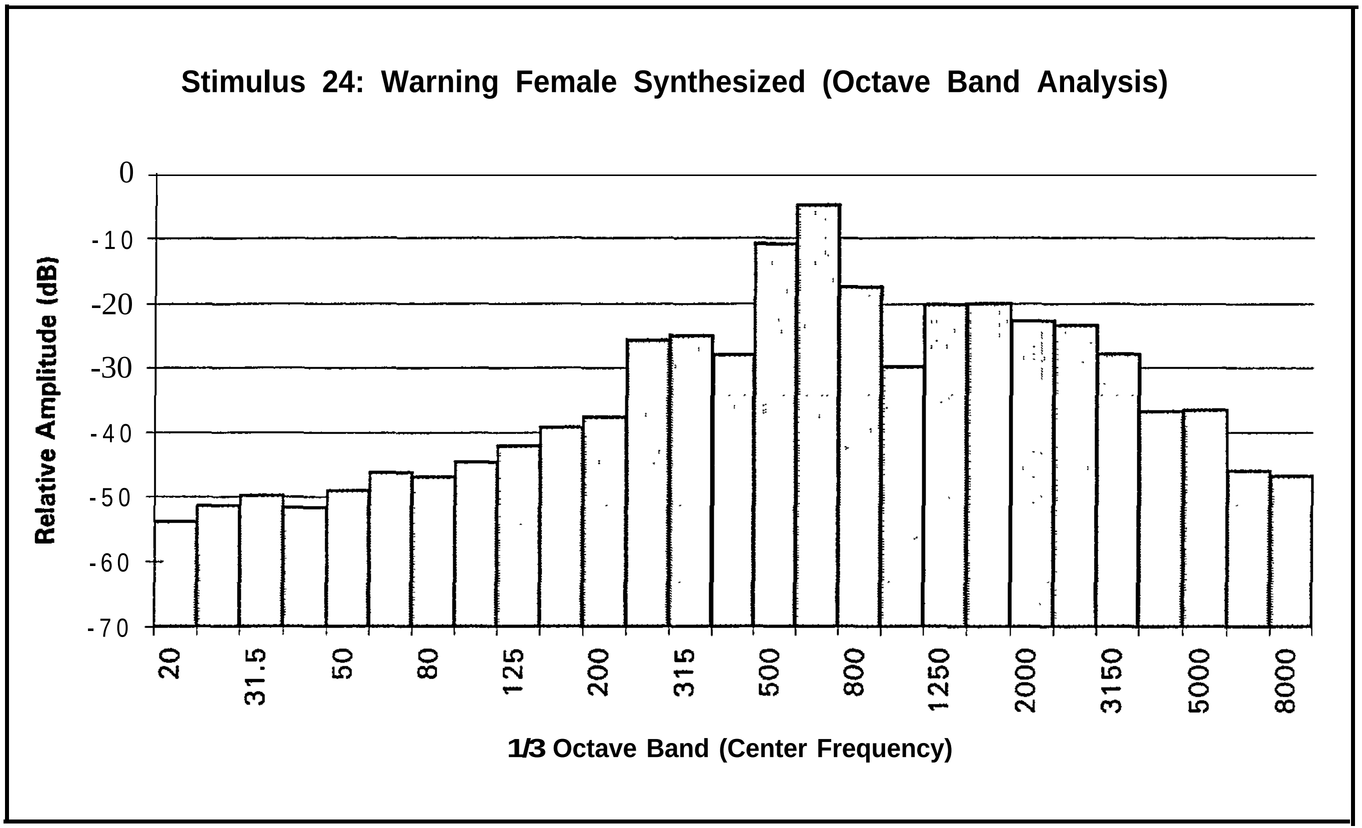


Stimulus 22

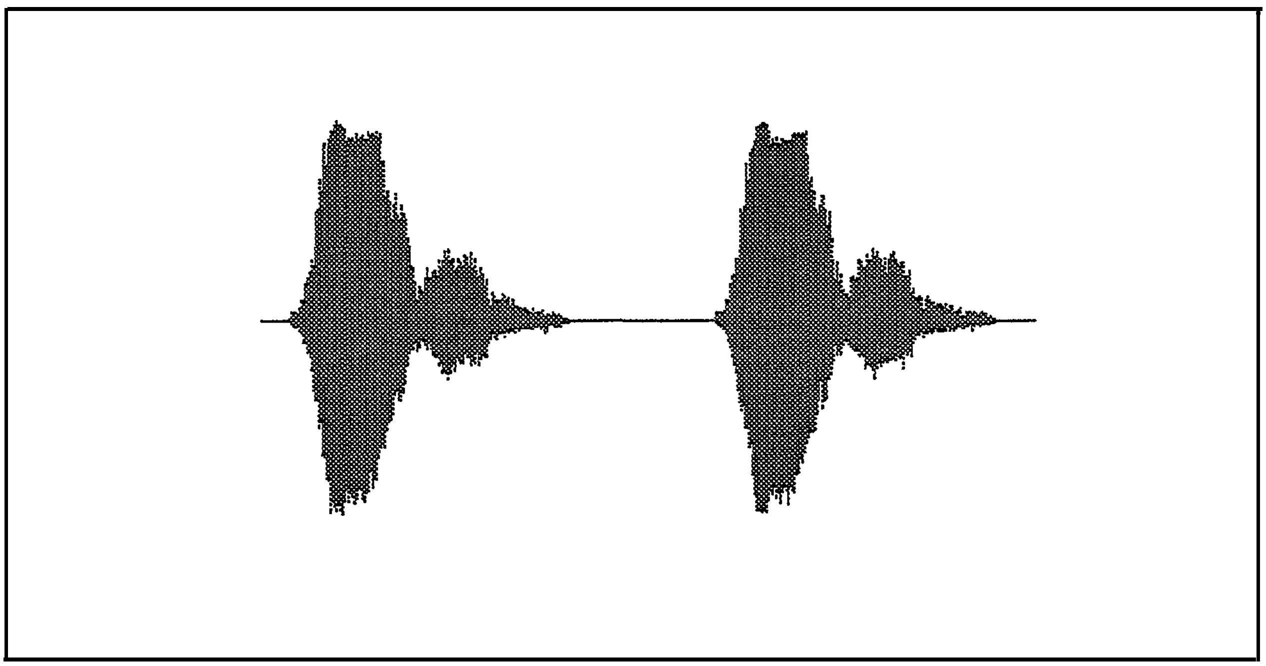

Stimulus 23: Danger Female Synthesized (1/3 Octave Band Analysis)
0
-10
-20
-30
-40
-50
-60
-70
Relative Am (dB)
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)



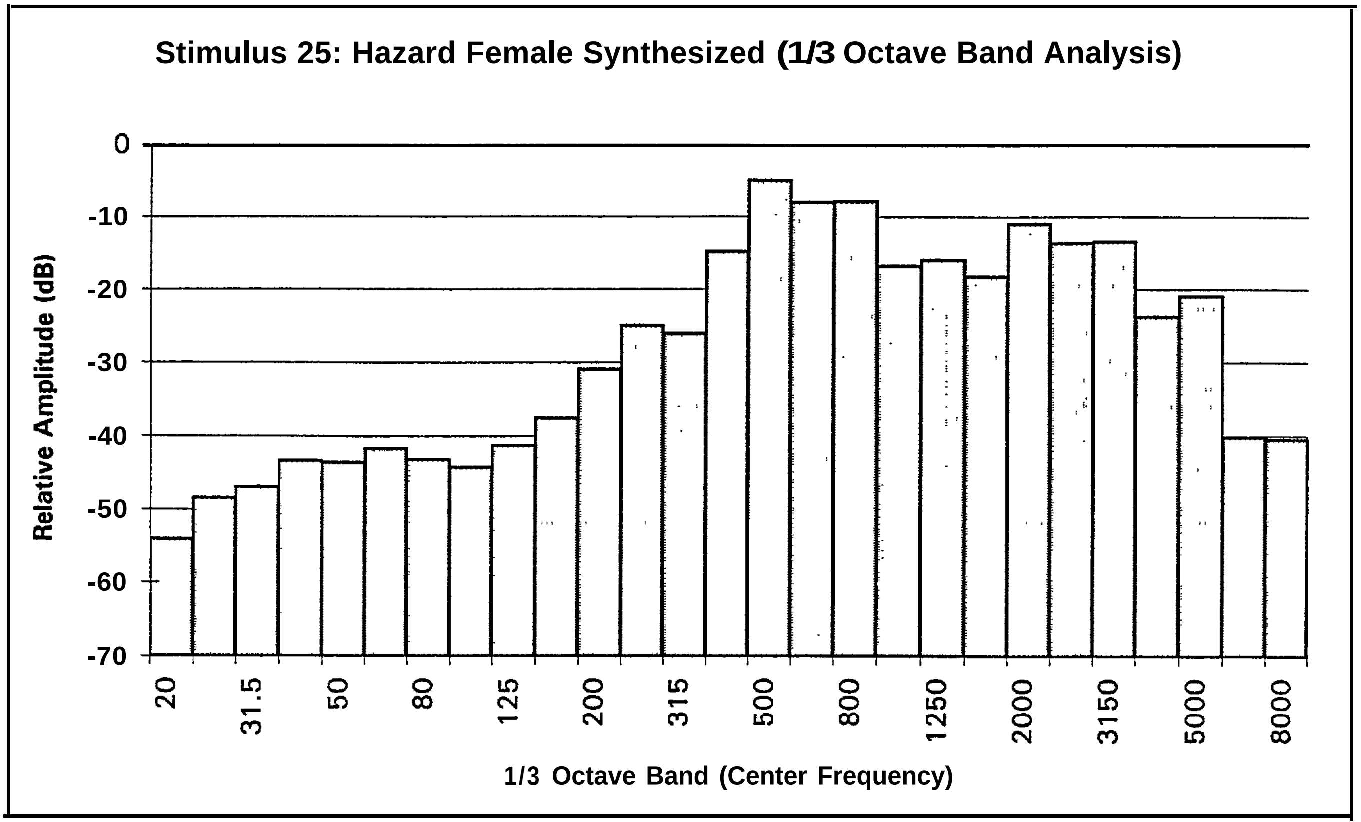
Stimulus 23

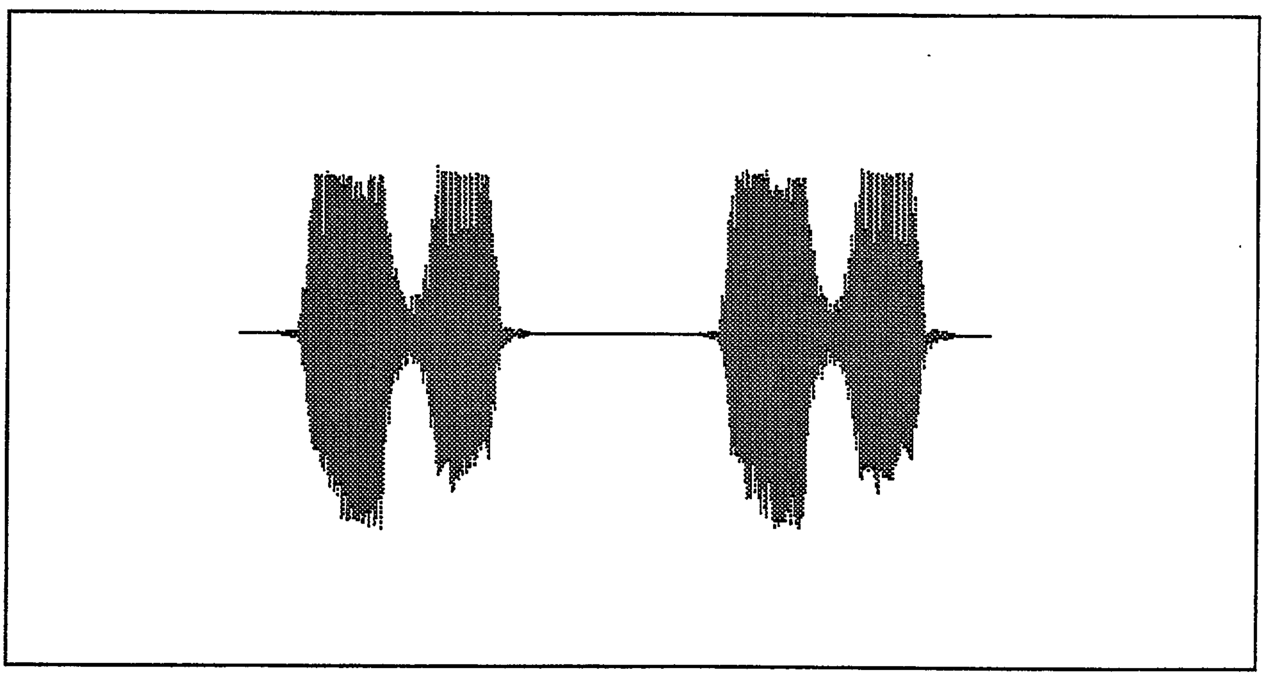


Stimulus 24: Warning Female Synthesized (Octave Band Analysis)
0
-10
-20
-30
-40
-50
-60
-70
Relative Amplitude (dB)
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)

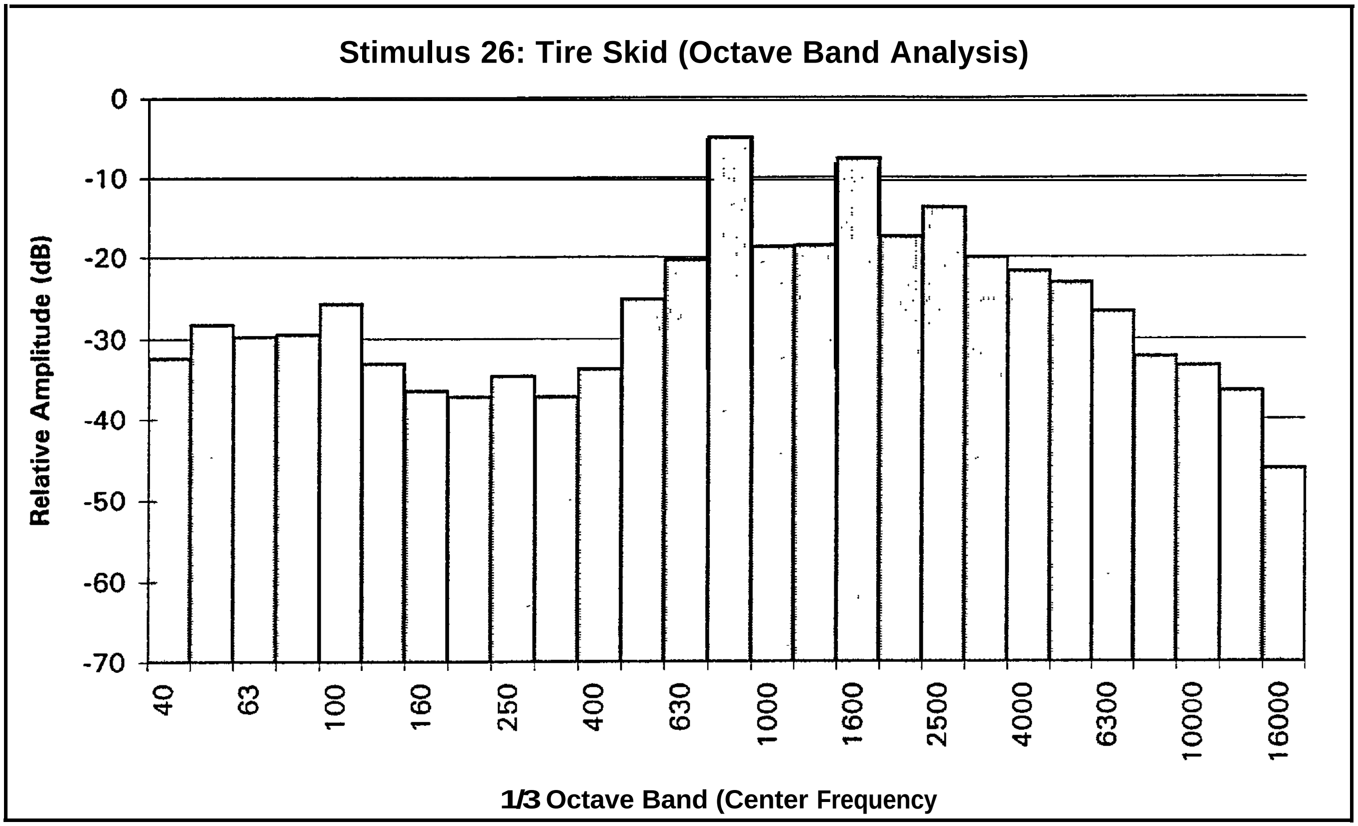


Stimulus 24

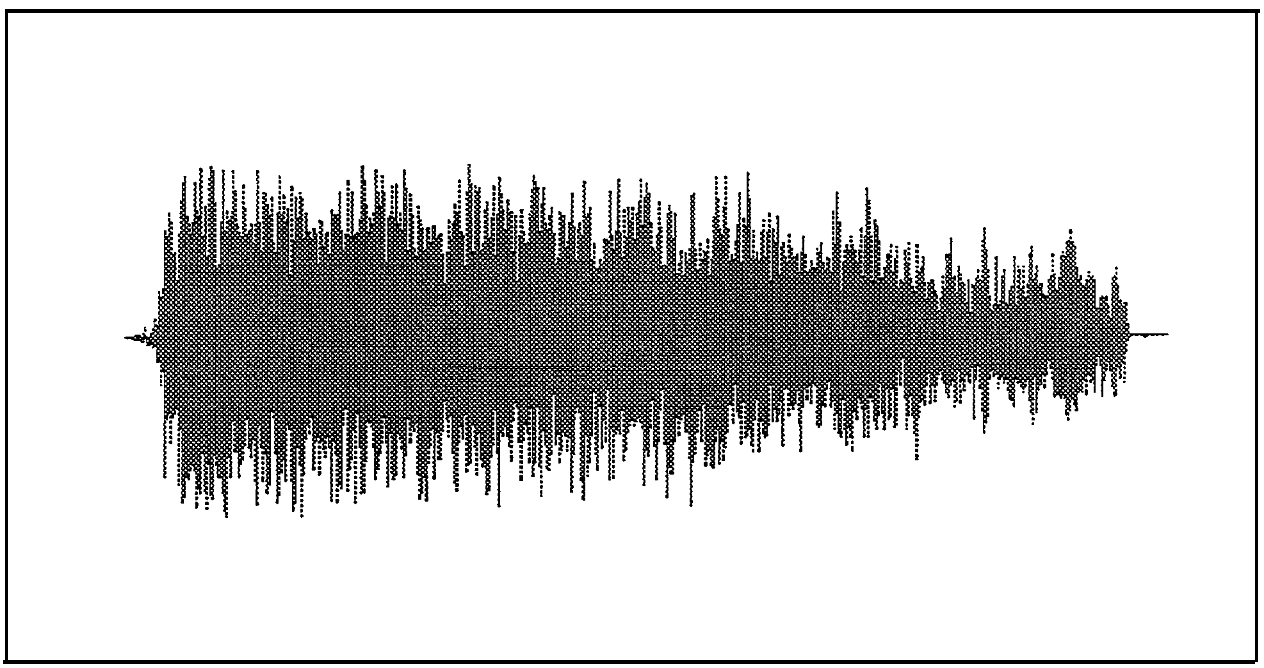

Stimulus 25: Hazard Female Synthesized (1/3 Octave Band Analysis)
0
-10
-20
-30
-40
-50
-60
-70
Relative Amplitude (dB)
20
31.5
50
80
125
200
315
500
800
1250
2000
3150
5000
8000
1/3 Octave Band (Center Frequency)



Stimulus 25



Stimulus 26: Tire Skid (Octave Band Analysis)
0
-10
-20
-30
-40
-50
-60
-70
Relative Amplitude (dB)
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
1/3 Octave Band (Center Frequency



Stimulus 26

APPENDIX C: EXCERPTS FROM IMMINENT CRASH AVOIDANCE WARNING GUIDELINES

2.4 AUDITORY DISPLAYS.

Auditory displays include both acoustic and speech displays. When used in conjunction with visual displays, auditory displays provide the redundancy necessary for crash avoidance warning systems. Auditory displays are most effective if they are reserved for imminent crash avoidance warnings, but they may also be effectively used for cautionary warnings for certain devices. Auditory warnings should not be used for status displays.

2.4.1 CHARACTERISTICS OF AUDITORY IMMINENT CRASH AVOIDANCE WARNINGS.

Auditory displays are the recommended mode of display for imminent crash avoidance warnings. The auditory display for imminent crash warnings should be distinctive and reserved only for crash avoidance warnings. The warning may be either an acoustic signal or a voice message, but the imminent crash avoidance warning should be consistent across crash avoidance devices. In the absence of a standard acoustic and voice display, refer to Sections 2.4.5 and 2.4.6 for recommendations for acoustic and speech displays, respectively.

Numerous studies support the superiority of auditory displays in terms of alerting value and reaction time (Horowitz & Dingus, 1992; Lilliboe, 1963; Teichner, 1954), particularly in situations in which alerting the individual is of prime importance. In an imminent crash avoidance situation, the alerting value of a display and the reaction time to a display are overriding concerns. Therefore, auditory displays are recommended. Although tactile warnings are permitted as an alternative to an auditory mode of display, the current state of knowledge regarding tactile warning displays suggests that auditory warnings should be favored, except where it is clearly demonstrated that the tactile display is as effective as an auditory display.

2.4.2 CHARACTERISTICS OF AUDITORY CAUTIONARY CRASH AVOIDANCE WARNINGS.

Auditory displays should not be used for cautionary crash avoidance warnings unless the advantages of using such displays outweigh the disadvantages.

There is a design trade-off between the advantages of auditory displays, which include superior alerting capabilities and reduced reaction times, and their disadvantages, which include their potential for annoying the driver in the case of frequent false or nuisance alarms (Butler, Manaker, and Obert-Thorn, 1981; Randle, Larsen, and Williams, 1980) and the possibility that such displays may create auditory clutter (Patterson, 1982). In addition, auditory warnings may not be perceived in noisy driving environments. Therefore, the designer must consider these trade-offs when deciding whether an auditory display is appropriate for cautionary crash avoidance warnings. Because of the possibility for multiple crash avoidance warning devices in the vehicle, the potential for annoyance and intrusiveness is increased, due to an increase in the rate of false and nuisance alarms. Visual cautionary warnings are preferred for any device except where important advantages of cautionary auditory displays can be demonstrated, and user acceptance is high.

2.4.3 AUDITORY DISPLAYS FOR STATUS INFORMATION.
Auditory displays should not be used to provide status information.

In order to preserve the saliency of auditory signals for warnings, they should not be used to convey status information. Additionally, drivers will quickly adapt to the auditory signals or, on the other hand, may turn them off. The resulting adaptation will decrease the effectiveness of the warning signal.

2.4.4 SOUND SOURCE LOCATION.
Tbe apparent source of an auditory warning should be consistent with the direction of the hazard.

Because of rapid advances in auditory display technology (e.g., 3-dimensional auditory displays), the location of the sound source conveying auditory information is less important than the location from which the sound ***appears*** to emanate.

2.4.4.1 Cuing for Directional Hazards.
Devices which provide auditory warning directional information should locate the sound source such that the warning appears to emanate from the position in tbe vehicle which is closest to the location of the target or crash situation which triggered the warning.

Auditory warnings can be used to provide directional information because humans are, in general, very good sound localizers (McFadden and Pasanen, 1976; Mills, 1958). Three-dimensional auditory display technology is beginning to mature and may soon be available in a variety of applications, allowing for the presentation of auditory information at virtually any location. If such technology is not cost-effective, auditory warning directional information can be conveyed through, for example, the use of the four stereo speakers in the vehicle or through the appropriate location within the vehicle of the crash avoidance warning device speakers (see Section 2.4.4.3 for limitations on use of displays directly ahead of or behind the driver).

2.4.4.2 Cuing for Non-Directional Hazards.
Tbe auditory warning for non-directional hazards should be presented such that the driver's attention is directed to the driver's line of sight of the roadway ahead or toward a visual display that specifies the nature of tbe hazard.

Non-directional hazard warnings should serve to heighten the driver's awareness of the driving situation, and should not be confused with directional crash avoidance warnings. By directing the driver's attention to the roadway ahead or to a visual display, the tendency for confusion with directional crash avoidance will be reduced, while still increasing the driver's general awareness of the hazardous situation.

2.4.4.3 Auditory Displays In Front of and Behind the Driver.
Auditory warnings that are presented to the front or rear of the driver should not be presented in the median plane (i.e., the plane perpendicular to the horizontal plane which passes through the driver's ears).

Although humans are generally good sound localizers, they have difficulty identifying sounds directly above, in front of, or behind them, without some head movement. As a result, front-to-back perceptual confusions occur frequently (Blauert, 1969/1970; Makous and Middlebrooks, 1990). However, even slightly offsetting the location of such sounds by a few degrees to the right or left eliminates this problem because of the acute human perceptual sensitivity to inter-aural time differences (McFadden and Pasanen, 1976).

2.4.5 CHARACTERISTICS OF ACOUSTIC DISPLAYS.
Acoustic displays (i.e., all auditory displays except speech displays) may be used for imminent and cautionary crash avoidance warnings. Acoustic displays may be used to alert the driver that a crash situation exists, assist the driver in locating the target or crash situation, and convey hazard proximity.

2.4.5.1 Coding of Levels of Warning.
Acoustic displays used for imminent crash avoidance warnings **should convey more urgency than other types of acoustic crash avoidance warnings present in the vehicle. The following characteristics may be used to differentiate imminent from cautionary acoustic crash avoidance warnings:**

IMMINENT	CAUTIONARY
high signal (or pattern) repetition rate	**low signal (or pattern) repetition rate**
high intensity	**low intensity**
high fundamental frequency	**low fundamental freauencv**
large frequency oscillations within auditory patterns	**small frequency oscillations within auditory patterns**

Edworthy, Loxely, and Dennis (1991) enumerate the sound characteristics that increase the perceived urgency of a warning signal, and the preceding guideline is largely based on their work. Additional work conducted by Peio and Dolan (1992) supports this recommendation.

2.4.5.1.1 Intensity Coding.
Intensity coding should not be used to distinguish among **the levels of warning of a crash avoidance warning device or system.**

Intensity coding is generally not recommended because people are poor judges of absolute levels of intensity (Van Cott and Kinkade, 1972). Although imminent crash avoidance warnings may be conveyed at a greater intensity than cautionary crash avoidance warnings, other auditory characteristics besides intensity should be used to code the level of warning.

2.4.5.1.2 Duration Coding.
Duration coding is not recommended for auditory crash avoidance warning displays. Pattern of tones may be used (see Section 2.4.5.8).

Drivers' inabilities to judge absolute signal duration in the absence of a comparison tone will require that duration differences be quite large. Because of this, the overall time required to present the signal would be so long as to delay driver response.

2.4.5.2 Fundamental Frequencies.
Sounds having fundamental frequencies between 500 and 3000 Hz are recommended for acoustic crash avoidance warnings. If frequency is used as a code to distinguish among the levels of warning of a device or system, the fundamental frequencies chosen should be broadly spaced over the 200 to 3000 Hz range (e.g., 200,1600, and 2800 Hz instead of 200, 300, and 400 Hz). The frequencies chosen should be those least subject to masking by ambient noise. In accordance with Section 2.4.5.1, if frequency is used to code levels of warning imminent crash avoidance warnings would have the highest fundamental frequency.

Fundamental frequency values are well established in the auditory warning literature, (VanCott and Kinkade, 1972; Morgan, Cook, Chapanis, and Lund, 1963; MIL-STD-1472D; NUREG 0700). However, both Veitengruber, Boucek, and Smith (1977) and Berson, Po-Chedley, Boucek, Hanson, Leffler, and Wasson (1981) caution that frequencies should be chosen with due consideration of the noise characteristics of the operational environment.

2.4.5.3 Spectral Characteristics.
If a single sound is used for a crash avoidance warning, a complex sound should be used, as opposed to a pure sinusoidal waveform. Variations in spectral characteristics may be used to code levels of warning.

Complex sounds are more easily identified than pure tones. Pure tones also tend to be annoying to the listener. Because complex sounds contain a variety of perceptual cues, it is easy to create numerous signals that can be easily differentiated and absolutely identified. Pure tones, in contrast, are less "rich" and can be identified only on the basis of their frequency (Van Cott and Kinkade, 1972; Morgan, Cook, Chapanis, and Lund, 1963; MIL-STD-1472D; NUREG 0700).

2.4.5.4 Default Warning Intensity.
At the driver's ear, default intensity values for acoustic warnings should be at least 20dB, but no more than 30dB, above the masked threshold based on ambient noise for relatively noisy operating conditions.

Antin, Lauretta, and Wolf (1991) recommend that acoustic warnings be at least 20 dB above masked threshold, but should not exceed the masked threshold by more than 30 dB. The perceived intensity of sound depends on a number of factors, most notably-the location of the sound source with respect to the driver's ear. Therefore, optimum default intensity values may differ depending on the location of the sound source and any obstructions that block the path of the sound.

2.4.5.5 Onset and Offset Rates.
Tbe onset rate for sounds or tones used in crash avoidance warnings should be rapid enough to alert the driver, but not so rapid as to induce severe startle effects. Onset rates of greater than 1 dB/msec but less than 10 dB/msec are recommended. The offset rate should be equal to the onset rate.

According to Woodson and Conover (1964), sounds with onset rates less than 1 dB/msec are perceived as continuously rising and produce little or no startle effects. Sound with onset rates of 10 dB/msec appear instantaneous and will produce moderate startle responses.

2.4.5.6 Warniug Duration.
A single sound or tone used as a crash avoidance warning signal should be between 200 and 500 msec in duration. If complex tones, as opposed to pure tones, are used, durations near the bottom of tbis range (e.g., 200-300 msec) are recommended.

Tones less than 200 to 500 msec in duration are not perceived. as very loud, and are easily missed in a noisy environment (Sanders and McCormick, 1993). There is, in addition, a trade-off between intensity and duration. The shorter the duration of the tone, the greater its intensity needs to be (Sanders and McCormick, 1987). It is important from a reaction time perspective to keep the off-time of the repetition cycle short since the driver is not receiving useful information during the off period.

2.4.5.7 Warning Repetition.
If a single sound or tone is used as a crash avoidance warning signal, it should be repeated for as long as the crash avoidance warning condition exists, or until the system or device recognizes some corrective action on the part of the driver. The criterion that applies depends on the type of device, as noted in the specific guidelines sections.

2.4.5.8 Use of Auditory Patterns as Acoustic Crash Avoidance Warnings.
Continuously repeating auditory patterns, as opposed to repeating single tones or sounds, may be used for acoustic crash avoidance warning displays, provided they are of short

duration or cycle time. Such patterns should be easily learned and perceived and be absolutely identifiable by the driver.

Limited research exists concerning the use of complex auditory patterns, as opposed to individual sounds or tones, to convey warning information. Their potential is only now being investigated (May, 1993), and use of complex auditory patterns in the future should not be ruled out.

2.4.5.9 Conveying Time- or Distance-to-Collision Information.
Acoustic displays may convey time- or distance-to-collision information (i.e., graded waruiugs), if such information is provided for a particular crash avoidance warning device. The following means of conveying this information through acoustic displays are recommended:

a. **Warning repetition rate increases as time- or distance-to-collision decreases; repetition rate decreases as time- or distance-to-collision increases.**

b. **Fundamental frequency of warning tones increases as time- or distance-to-collision decreases; fundamental frequency of warning tones decreases as time- or distance-to-collision increases.**

c. **Intensity of warnings increases as time- or distance-to-collision decreases; intensity of warnings decreases as time- or distance-to-collision increases.**

These manipulations of acoustic warnings are based on the work of Edworthy, Loxely , and Dennis (1991). As time- or distance-to-collision decreases, warnings can be made to sound more urgent through the suggested manipulations. Likewise, as the collision threat decreases, the warnings are perceived as less urgent.

2.4.6 CHARACTERISTICS OF SPEECH DISPLAYS.
Speech warning displays should be highly intelligible, but readily distinguishable from the normal human voice. Speech displays may be used to present imminent and cautionary crash avoidance warnings. They should serve an alerting function and may also provide directional information. Speech displays are not recommended for providing time- or distance-to-collision information.

Drivers may find it difficult to discriminate digitized speech from both passenger and radio speech present in the vehicle. Therefore, the voice employed for speech warnings, whether synthesized or digitized, should be readily discernible from the human voice.

Generally, more time is required to deliver a speech message than to alert the driver through other modes. For this reason, speech displays are not recommended for presenting specific information of a dynamic nature. Acoustic displays, which can cycle quickly, are capable of providing such information more succinctly than speech displays.

2.4.6.1 Message Length.
Speech warnings should be as brief and concise as possible (e.g., one to three words).

There is limited time available for the presentation of speech messages in crash avoidance situations. Therefore, messages must be short, generally between one and three words. However, in applications where time availability is not a critical factor, longer messages are preferred, because they allow the listener to accommodate to the synthetic speech, thereby increasing its intelligibility. Although this "ramp-up" time is short, it is normally desirable in other contexts in which time pressure is minimal (Rosson, 1985; Thomas, Rosson, and Chodorow, 1985).

2.4.6.2 Vocabulary.
The vocabulary used for speech messages should be limited in size, and should consist of words which can be easily discriminated from one another. If sufficient time is available, polysyllabic words are recommended over monosyllabic words.

Since messages must be brief, and the driver will have little time or opportunity to adapt to synthetic speech, the vocabulary must be limited. Because short messages will be presented in isolation, the driver will not be able to identify the words based on context cues. The vocabulary, therefore, should consist of words that are easily discriminated by the driver. Hart and Simpson (1976) have demonstrated that polysyllabic words are more easily recognized than monosyllabic words in some contexts and environments.

2.4.6.3 Message Content.
The content of speech messages should be limited to that which alerts the driver to the crash avoidance situation and directs the driver's attention to its location. Imminent and cautionary speech messages should be differentiated by their message content. Stronger language should be used for imminent than for cautionary warning messages.

Auditory displays, generally speaking, have good alerting capabilities. Given the limited time available to convey crash avoidance messages via the speech mode, the alerting function should be exploited. Because direction can be conveyed easily with minimal vocabulary or through the location from which the speech appears to emanate, directional information may also be conveyed. More complex forms of information (e.g., time- or distance-to-collision) should not be incorporated into speech messages.

There are few recommended ways in which speech displays can be coded to differentiate imminent and cautionary conditions. The most obvious way is through differences in content (i.e., "Danger" for imminent warnings; "Caution" for cautionary warnings). Other means of indicating urgency have been explored, including speech rate and voice pitch (Simpson and Marchionda-Frost, 1984), but testing of candidate frequencies and rates would be needed before such techniques could be recommended for use in crash avoidance warnings.

2.4.6.4 Message Presentation.
The speech delivery system used to convey crash avoidance warnings should be one which demonstrates a high level of intelligibility in tests using isolated words. Candidate systems should demonstrate high intelligibility of the specific vocabulary to be used in tbe warnings.

Due to the small vocabulary and limited message length, intelligibility measures based on conversational speech intelligibility will be less relevant in choosing a system than measures based on the intelligibility of isolated words (Moore, 1985). In addition, synthetic speech systems, which are largely rule-based, differ from one another with respect to the pronunciation and intelligibility of individual words. Although many systems exist which have merited high scores on intelligibility tests, a confirmation of the specific vocabulary to be used is, nevertheless, recommended. Studies (Nixon, Anderson and Moore, 1986) also indicate that higher quality synthetic speech systems are generally more intelligible in noisy environments.

2.4.6.5 Message Repetition.
A given speech warning should be presented no more than three times for a given crash avoidance warning situation, regardless of the duration of the situation. Repetitions should occur in immediate succession. If the duration of the crash avoidance condition is less than the time required to deliver the three presentations of the speech message, the speech message should be terminated when the crash avoidance situation terminates.

Voice messages should not be repeated numerous times because of their tendency to irritate the driver and upset passengers. Voice messages will be more disturbing, particularly to passengers, than any other type of warning, if repeated frequently in succession. In addition, the potential for embarrassing the driver and creating a panic situation is greater for speech displays than for other displays. The three-presentation limit is based on the Traffic Collision Avoidance System (TCAS) used in aviation, which also provides two and, for some messages, three presentations of collision avoidance warnings and instructions (Federal Aviation Administration, 1990).

2.4.6.6 Use of Multiple Languages for Speech Warnings.
Speech technology used for crash avoidance warning devices and systems may incorporate multiple language options. Crash avoidance warning vocabularies and messages should be developed and tested separately for each language to be represented within the system or device.

Crash avoidance warning device or system developers cannot assume that messages developed for use by the English-speaking population can be translated directly into other languages. Nor can they assume that words that are highly discriminable in English will be highly discriminable in other languages.

Vocabularies and speech messages must be developed and tested separately for each language to be employed in a crash avoidance warning application.

2.4.6.7 Voice Characteristics.
The voice characteristics of speech displays should be such that the synthetic messages can be easily differentiated from other speech in the vehicle (e.g., passengers talking, or speech on the radio). The voice characteristics should yield a clearly mechanical, authoritative, voice, but not an unpleasant (e.g., tinny) one.

Speech messages must be differentiable from other speech in the vehicle. In an aircraft situation, for example, in which most of the flight crew is male, female synthetic speech messages are often employed. This reasoning, however, is not as applicable in the driving environment. The most obvious way to differentiate synthetic speech is to make it sound clearly non-human. A number of researchers (Brown, Bertone, and Obermeyer, 1986) advocate doing this. Gardner-Bonneau (1989) found, in a telephone application for American Express, that the more rigid and mechanical a voice sounded, the more commanding it appeared to be and the more compliant listeners were with respect to instructions presented in synthetic speech. It is also true, however, that listeners may reject synthetic speech if it sounds too robotic and stilted. Hence, care must be taken to ensure that the voice characteristics achieve a perception of authoritativeness, without a cold, robotic tone to the message.

2.4.6.8 Speech Warning Presentation Rate.
A speech warning rate of 156 words per minute is recommended, although slightly higher rates (up to 200 words per minute) may be used (e.g., 2 to 3 words per second).

Simpson and Marchionda-Frost (1984) found an optimal speech rate of 156 words per minute, although the pilots in their study had no difficulty understanding synthetic speech at 178 words per minute, the highest rate used in the study. Conversational speech can be comprehended at more than twice that presentation rate, with minimal adaptation time (Goldhaber and Weaver, 1968). However, the results of one recent study (Tun, Wingfield, Stine, and Arthur, 1992), which employed synthetic speech rates from 140 to 280 words per minute, indicated that older adults' immediate memory performance was depressed when speech rates were very fast. Therefore, a rate of 156 words per minute is recommended. Rates slightly higher than this are acceptable.

2.4.6.9 Speech Warning Intensity.
The speech warning should be loud enough to be clearly intelligible in all anticipated operating environments.

The appropriate intensity level for speech warnings depends on the noise level in the ambient environment, the distance of the speech source from the driver, characteristics of the speech signal, the design of the speech system, and other factors. It is quite possible that data and recommendations concerning the perception of natural speech in noise (Kryter, 1972; Peterson and Gross, 1978) would apply to synthetic speech as well, but no existing studies make this comparison.

2.4.6.10 Use of an Alerting Tone Preceding Speech Messages.
Au alerting tone should not be used preceding voice messages unless its benefits in the crash avoidance context can be demonstrated.

A number of studies (Bertone, 1982) and standards (MlL-STD-1472D) recommend the use of an alerting tone preceding speech warning messages, because the tone can speed response to the speech message to some extent. However, such tones may not be appropriate in the crash avoidance context because of the limited time available to present crash avoidance information. The presentation of an alerting tone and a pause prior to the presentation of the speech warning would add approximately one-half second to the presentation. Furthermore, the facilitation of the alerting tone may be minimal, given that messages are brief, repeated, and easily distinguished from other speech in the vehicle. Simpson and Williams (1980), Wheale (1980), and Thomas, Rosson, and Chodorow (1984) indicate that an alerting tone is not needed if synthetic speech is used only for warnings in the operational environment. Even if this is not the case, these authors indicate only that an alerting tone *might* be necessary. TCAS, for example, does not employ an alerting tone prior to speech messages (Federal Aviation Administration, 1990). The benefits of an alerting tone in this application remain untested and unverified. Clearly the ability of a particular voice message to initiate the proper response in the time available must be verified for each device.

APPENDIX D: MAE SESSION DEMOGRAPHICS FORM

NAME/ADDRESS

____ Participant ID Number ____ SESSION

Participant Name: ____________________

Address: ____________________

____

____

Home Phone: ____________________

Work/Daytime Phone: ____________________

PARTICIPANT PRESCREENING/DEMOGRAPHICS

Criteria:

_____ Has Valid Driver's License

_____Age (between 20-40; 65+)

_____(yes/no) Do you have any hearing problems?

PLEASE EXPLAIN:

____

_____ Estimated number of hours of driving per week
(no req., information only)

_____ Estimated number of miles driven per week
(no reqs., information only)

Demographic Information:

Gender:

_____Male _____Female

_____Number of years of driving experience

Type of Car.

Make ____

Model ____

Year ______________

Type of transmission:

_____Automatic _____Manual

Primary driving purpose:

_____ Commuting to and from work

_____ As part of your job

_____To run household errands and chores (e.g., grocery shopping, chauffeuring children)

_____Pleasure or leisure

_____ Other __________________________________

_____ Session ID

APPENDIX E: CONSENT FORM

CONSENT FORM
IN-VEHICLE WARNINGS

<u>Purpose of the Research</u>: Under contract with the National Highway Traffic Safety Administration (NHTSA), COMSIS is investigating the effectiveness of various warning sounds through studies such as this one. The purpose of this research is to collect information about drivers' perceptions of various sounds--we are interested in how you rate the sounds on various attributes.

These sounds may soon be used for warning systems in future intelligent vehicles, such as a system that would alert you when objects which you may not be aware of are in your "blind spot" or of a nearby car that is encroaching on your lane and into your path. An auditory tone or light may alert you to these hazards so that you can better avoid them. The problem with many warning signals today is that they do not convey information in an appropriate manner. Your feedback will help to determine guidelines for the development of in-vehicle crash avoidance warning alarm sounds.

<u>Research Procedures</u>: In this session, you will be asked to listen to various sounds and rate these sounds on 10 different attributes. For each attribute, you will be asked to rate the sounds on a scale of 1 to 7 on how much each sound reflects or does not reflect the attribute. You will work in a group setting, but the answers must be your own.

<u>Foreseeable Risks</u>: There are no unusual risks associated with participating in this study, other than those normally associated with being in an office. All sounds and noises that you hear are below the Occupational Safety and Health Administration (OSHA) sound level regulations9i.e loudness levels) for noise in order to protect your hearing.

<u>Benefits of the Research</u>: The findings of this study will be used to develop guidelines for the development of in-vehicle warning systems. As a result of this research, sound types that are inappropriate will be eliminated from consideration, and all remaining sounds will be compared to determine the most useful ones. The types of sounds found to be appropriate will then be further researched. The determination of an optimal warning could result in a driving environment that is more safe, comfortable, and usable by the full range of the driving public.

You will be paid $20 for your participation in the session. If the investigator must terminate the session earlier than planned, you will still be paid the full amount.

<u>Confidentiality</u>: We will ask to look at your driver's license to confirm your age and your driving status, and ask how long you have been driving, how often you drive, and about your hearing. Additional information about the type of vehicle you drive will also be collected. This information is confidential, and no published

reports of the research will identify any participant. Likewise, all information collected during the study is confidential and will not be presented in any form that identifies individuals.

<u>Contact Person</u>: If you have any questions about the research or the rights of research participants, you may contact Dr. Ron Lyons, Project Director, Human Systems Design, COMSIS Corporation, 8737 Colesville Road, Silver Spring, MD 20910; [telephone (301) 588-08001.

<u>Voluntary Withdrawal from the Experiment</u>: Your cooperation in this study is entirely voluntary. You may withdraw participation at any time. If you withdraw from the study, you will be paid on a prorated basis for the time you did participate.

AUTHORIZATION: I have read the above and recognize the risks of this study. 1 agree to participate as a subject in the research. I also understand that participation is voluntary and I may withdraw from the study at any time.

Signature of Participant: ___________________________ Date: ______

(printed name): ___________________________

Signature of Investigator: __________________________ Date: ______

FOR OUR RECORDS

Address: ____________________________________

____

DOB: ____________________

If you are interested in being contacted occasionally for further research please leave your phone number below:

____

APPENDIX F: SESSION INSTRUCTIONS

INSTRUCTIONS FORM
IN-VEHICLE WARNINGS STUDY

Greet subjects. Hello, my name is _______________. How is everyone today?

Today, we are asking you to make judgments of various sounds based on 10 different attributes.

Under contract with the National Highway Traffic Safety Administration (NHTSA), COMSIS is investigating the effectiveness of various warning sounds through studies such as this one. The purpose of this research is to collect information about drivers' perceptions of various sounds--we are interested in how you rate the sounds on various attributes. You will be rating each sound you hear on 10 different attributes.

These sounds may soon be used for warning systems in future intelligent vehicles, such as a system that would alert you when objects which you may not be aware of are in your "blind spot" or of a nearby car that is encroaching on your lane and into the path of your car. An warning sound or light may alert you to these hazards so that you can better avoid them. The problem with many warning signals today is that they do not convey information in an appropriate manner. Your feedback will help to determine guidelines for the development of in-vehicle crash avoidance warning alarm sounds.

To give you a feel for the types of vehicle systems these sounds will be used for I'm going to show you a five minute video produced by NHTSA that overviews these future systems.

[SHOW VIDEO]

[ASK IF THERE ARE ANY QUESTIONS]

[HAND OUT AND EXPLAIN CONSENT FORMS]

For each sound attribute on which you will judge each sound, you will be presented with the definition of the attribute on the overhead projector and provided with an explanation of the the attribute. You will then listen to a string of sounds that you will rate on that attribute.

[SHOW PRACTICE SESSION ATTRIBUTE: MUSICALITY]

For example, for each attribute definition shown on the overhead, the name of the attribute will appear at the top, followed by the definition of the attribute (next to the diamond). For some attribute definitions, a second definition is provided to

help clarify the attribute definition. Below the definition area is the Question you are asked to answer (next to the "Q"). You should ask yourself this question for each sound you hear for that attribute, and you should refer to the definition if necessary to help you answer the question. The scale you will use to rate the sound appears below. It is a scale from 1 to 7. For example, for the attribute Musicality a 1 indicates that the sound is not very musical and a 7 indicates that the sound is very musical. The scale is the same one that appears on your response box. You will indicate your rating by pressing the appropriate button on your box after you hear each sound.

Are there any questions so far?

Once again, you will be presented with the definition of the current attribute to be rated on the overhead, and I will explain what the attribute means.

If you have any questions about the definition please feel free to ask questions at this time.

Otherwise, we ask that you do not ask questions or talk to others during the experiment. Following the definition, a series of sounds will be presented. Please rate each sound based on the defined attribute and input your rating by pressing the appropriate button on the response box..

Please be sure to rate the sound after it has been presented. If you enter a response before the sound is completed, your response will not be registered by the computer, so it is very important that you wait until the sound has finished playing before you respond. You will have approximately 5 seconds to make your response. If, during this time, you change your mind, simply press the button that corresponds to the rating that you would like to give. The computer will register the last response you make, so it is very important that the last response you make is your true opinion of that sound.

If the experimenter notices that any of you has not entered a response within 5 seconds, she/he will ask you to respond again. You will be referred to as participants I-8. Your box has your participant number.

Please be ready to listen and respond to the next sound after you input your response for the last sound. We will not be able to repeat the sound once they are played for the current attribute. If you miss a sound, please make your best shot at the rating.

You will rate about 25 sounds for each attribute. Please keep in mind that there are no wrong answers.

[Are there any questions?]

OK, again, during the rating of the sounds, we ask that you do not talk with one another or look at other peoples responses. We are interested in individual opinions and not a consensus. Unless you are experiencing problems with your input device, please hold your questions to the attribute definition portion of the experiment. The total experiment should last approximately 2 hours.

[ARE THERE ANY QUESTIONS].

Ok, then we'll run a practice session to get you familiar with the procedure, the input box and the types of sounds you will hear in the experiment.

Before we begin the practice session, we will ask you to test the seven buttons on your response box. This will be done one participant at a time. When the experimenter.cues you, please press each button on your box one at a time. If you are unsure if you hit the button correctly just **press it again.**

[TEST INPUT DEVICES]

Ok, now that everyone's input box has been tested, we'll go through a practice session to be sure you understand the task.

[START WITH MUSICALITY]

Are there any questions:

> **<IF YES>- ANSWER AND CLARIFY THEIR QUESTIONS>**
>
> **<IF NO > Okay, then let's begin the practice session..**

We will run through four attributes like this one and then take a short break so you can rest your ears and stretch your legs. After the break, we will run through another 3 attributes, take another break and then test the final 3 attributes.

ARE THERE ANY QUESTIONS?

OK, once again if you have any questions during the experiment, please ask them during the attribute definition portion of the experiment or during the breaks. Also, please wait until the sound has finished playing before inputing your response.

APPENDIX G: AITRIBUTE SLIDES

ATTRIBUTE TO LISTEN FOR:

ANNOYANCE

+The sound is annoying.

Q: How annoying is this warning?

NOT VERY						VERY
1	2	3	4	5	6	7

ATTRIBUTE TO LISTEN FOR:

APPROPRIATENESS

+The sound is compatible with the vehicle environment (e.g cars, trucks, etc.).

-I.e. The sound would not appear out of place if used as a warning in a car or truck.

Q: How appropriate would this sound be for a vehicle environment warning?

NOT VERY						VERY
1	2	3	4	5	6	7

ATTRIBUTE TO LISTEN FOR:

DISCRIMINABILITY

*The sound is uniquely identifiable and distinct from other sounds in the driving environment.

Q: How discriminable is this sound?

NOT VERY	←				→	VERY
1	2	3	4	5	6	7

ATTRIBUTE TO LISTEN FOR:

EMERGENCY RELATIONSHIP

+The sound follows relationships users have learned to associate with an emergency.

*i.e The sounds or words are usually associated with an emergency situation

Q: How compatible is this sound with your experience of What an emergency warning should sound like?

NOT VERY	←				→	VERY
1	2	3	4	5	6	7

ATTRIBUTE TO LISTEN FOR:

LOUDNESS

+The sound has high volume and intensity.

Q: How loud is this sound?

NOT VERY						VERY
1	2	3	4	5	6	7

ATTRIBUTE TO LISTEN FOR:

MEANING

◆The sound would be a good selection to clearly convey or suggest an immediate crash situation.

Q: How well does this sound convey or suggest an immediate crash situation.

NOT VERY						VERY
1	2	3	4	5	6	7

ATTRIBUTE TO LISTEN FOR:

MUSICALITY

+The warning is melodious and/or harmonious.

*i.e. The warning has musical qualities.

Q: How musical is the warning sound?

[redacted] ←——→ VERY

1 2 3 4 5 6 7

ATTRIBUTE TO LISTEN FOR:

NATURAL RESPONSE

+The sound naturally causes the driver to anticipate and prepare for an emergency.

i.e. Without prior learning, this sound implies an impending emergency situation.

Q: How well does this sound signify an impending emergency situation?

NOT VERY ←——→ VERY

1 2 3 4 5 6 7

ATTRIBUTE TO LISTEN FOR:

NOTICEABILITY

+The sound is readily noticeable among other sounds and noises in a vehicle.

0- i.e You can easily hear this sound within the vehicle noise.

Q : How noticeable is this sound?

NOT VERY ←						→ VERY
1	2	3	4	5	6	7

ATTRIBUTE TO LISTEN FOR:

STARTLE EFFECTS

+The sound produces startle.

=i.e You have a tendency to blink, jump, or exhibit rapid movements in response to the sound.

Q : How startling is the sound?

NOT VERY ←						→ VERY
1	2	3	4	5	6	7

ATTRIBUTE TO LISTEN FOR:

URGENCY

*The sound conveys a sense of importance, motivating you to make an immediate response.

Q: How urgent does this sound appear?

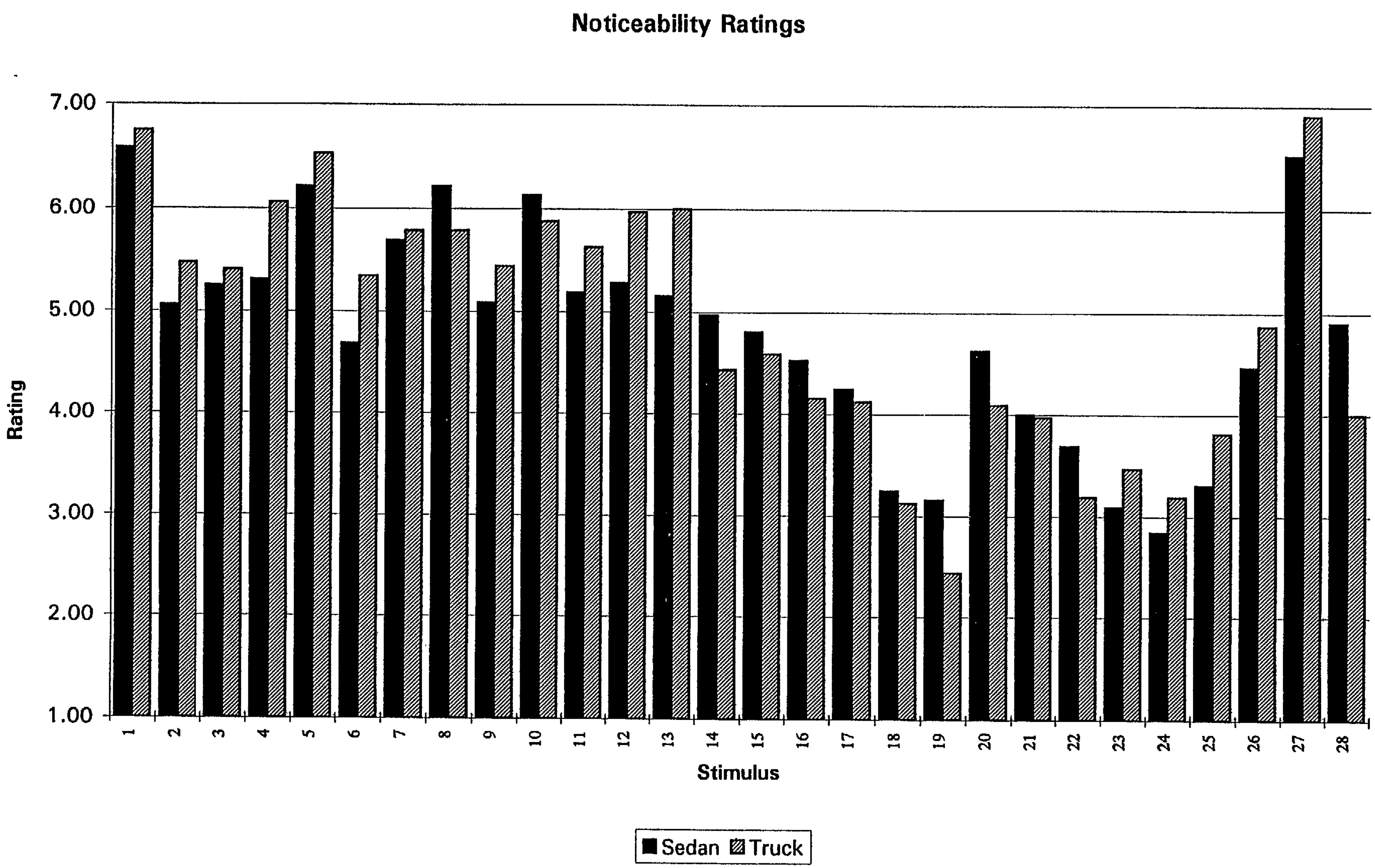
NOT VERY						VERY
1	2	3	4	5	6	7

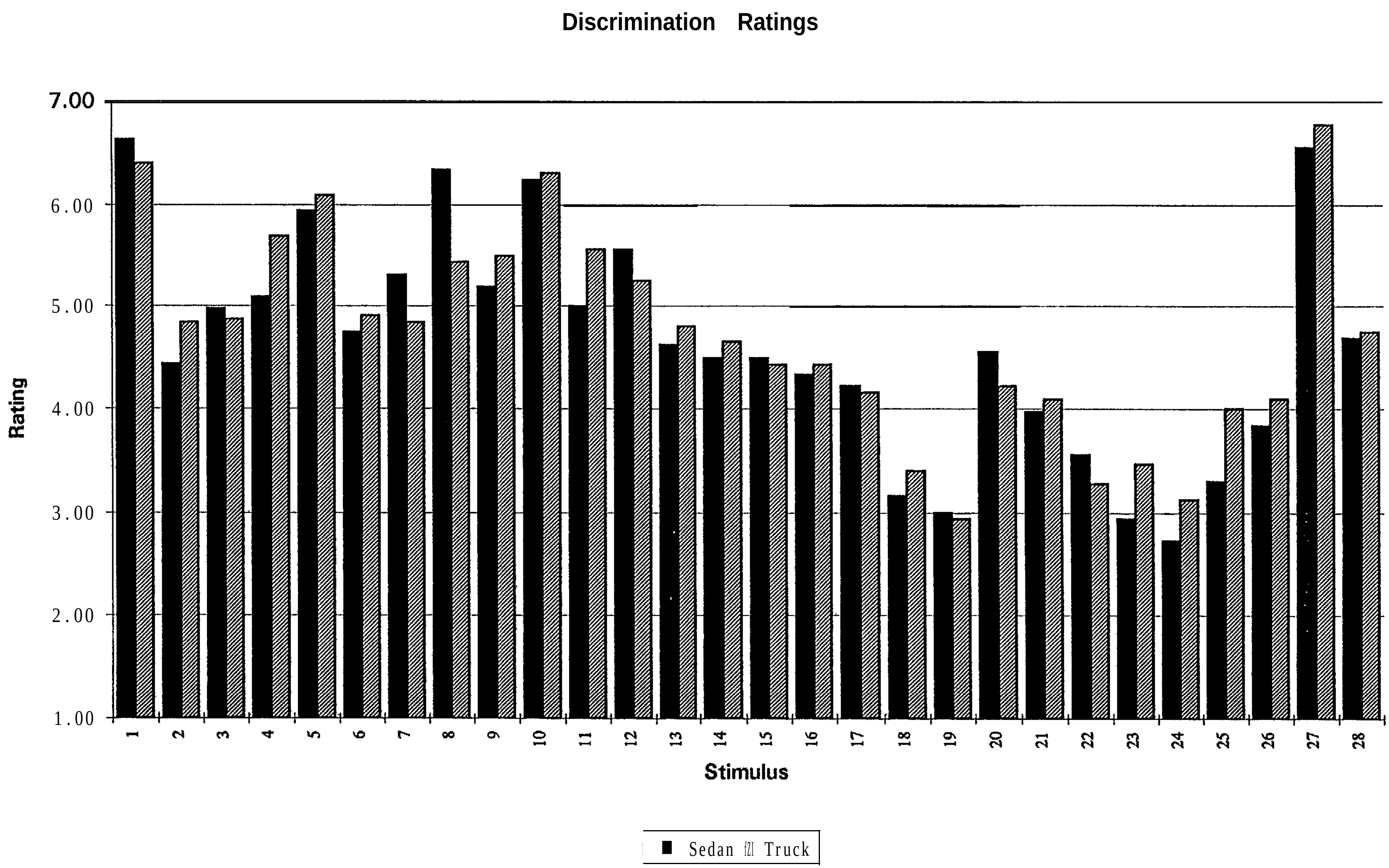
APPENDIX H: MAE MATRIX CALCULATION - TRUCK BACKGROUND NOISE

MAE Matrix Calculation - Truck Background Noise

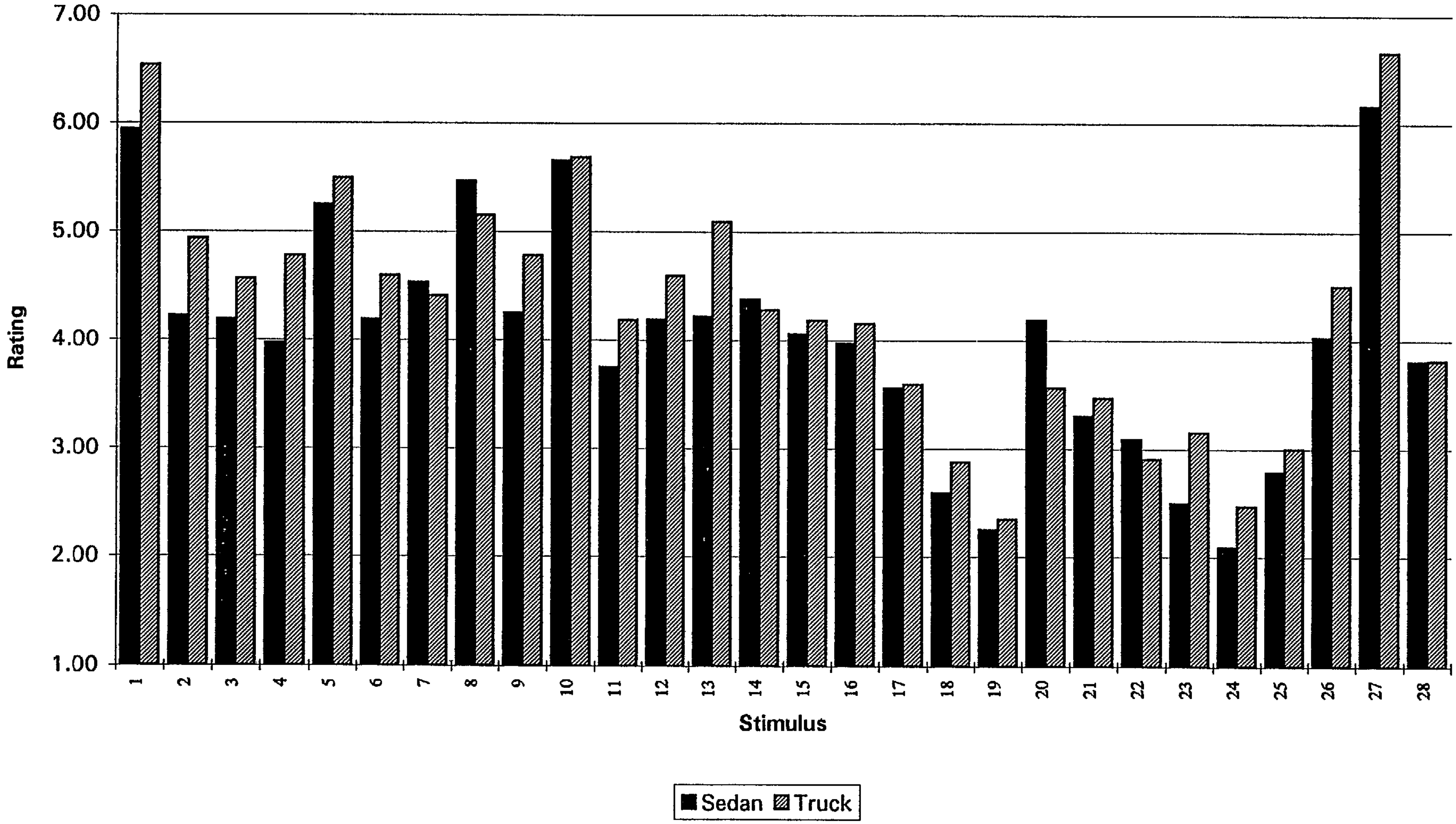
ATTRIBUTE	ANNO	APPR	DISC	EMER	LOUD	MEAN	MUSI	NRES	NOTI	STAR	URG	
EXPERT RATING	-4.37	5.66	9.23	7.63	0	9	2.26	8.63	9.43	-7.6	8.8	WEIGHTED
ALTERNATIVE												SCORE
1	6.22	5.50	6.41	6.63	6.41	6.53	3.38	6.53	6.75	6.47	6.66	309.47
2	4.88	4.94	4.84	5.28	5.59	4.94	3.72	5.44	5.47	5.44	5.31	248.41
3	4.56	4.69	4.88	4.78	5.03	4.56	3.91	4.66	5.41	4.84	4.38	230.81
4	4.56	4.97	5.69	4.94	5.75	4.78	5.13	5.19	6.06	5.59	5.03	256.67
5	5.56	5.66	6.09	6.06	6.06	5.50	4.81	5.88	6.53	5.69	5.84	291.08
6	5.16	3.91	4.91	4.16	5.22	4.59	2.97	4.53	5.34	4.81	4.75	219.35
7	4.69	4.66	4.84	5.00	5.56	4.41	3.16	4.84	5.78	4.94	5.25	240.51
8	4.41	5.38	5.44	5.47	5.22	5.16	4.56	5.16	5.78	5.09	5.28	266.58
9	4.81	5.03	5.50	4.97	5.13	4.78	4.25	4.75	5.44	5.03	4.69	244.04
10	5.19	5.28	6.31	5.88	5.44	5.69	4.56	5.56	5.88	5.78	5.66	281.06
11	4.84	4.41	5.56	4.50	5.13	4.19	4.84	4.41	5.63	4.66	4.66	234.74
12	4.47	4.72	5.25	4.22	5.53	4.59	4.91	4.66	5.97	5.16	4.78	239.61
13	5.13	4.84	4.81	5.31	6.09	5.09	3.47	5.47	6.00	5.44	5.69	256.16
14	3.09	4.69	4.66	4.44	4.25	4.28	2.78	4.66	4.44	4.03	4.38	224.56
15	3.09	4.59	4.44	4.41	4.31	4.19	2.81	4.75	4.59	3.78	4.25	224.08
16	3.06	4.22	4.44	4.03	3.94	4.16	2.78	4.19	4.16	3.81	3.94	206.91
17	2.72	4.28	4.16	4.19	3.69	3.59	2.72	4.03	4.13	3.13	3.97	206.02
18	2.31	3.31	3.41	3.28	2.47	2.88	2.50	2.84	3.13	2.44	2.88	157.43
19	2.00	3.03	2.94	2.91	2.16	2.34	2.31	2.81	2.44	2.06	2.72	139.53
20	2.75	4.09	4.22	3.78	3.75	3.56	2.59	4.03	4.09	3.41	3.50	195.17
21	2.72	4.03	4.09	3.63	3.53	3.47	2.75	3.59	3.97	2.78	3.38	190.82
22	2.19	3.34	3.28	3.34	3.06	2.91	2.44	3.16	3.19	2.59	3.25	163.01
23	2.19	3.47	3.47	3.41	2.75	3.16	2.53	3.34	3.47	2.75	3.16	170.65
24	2.56	3.22	3.13	3.13	2.56	2.47	2.66	3.00	3.19	2.41	2.69	149.25
25	3.06	3.63	4.00	3.66	3.22	3.00	2.25	3.56	3.81	3.03	3.34	177.12
26	4.56	3.38	4.09	3.97	4.50	4.50	2.19	4.59	4.88	5.03	4.94	203.50
27	6.47	5.91	6.78	6.72	6.88	6.66	3.75	6.84	6.91	6.94	6.75	318.26
28	3.63	5.11	4.75	4.59	3.91	3.81	5.03	4.31	4.00	3.25	4.09	223.90

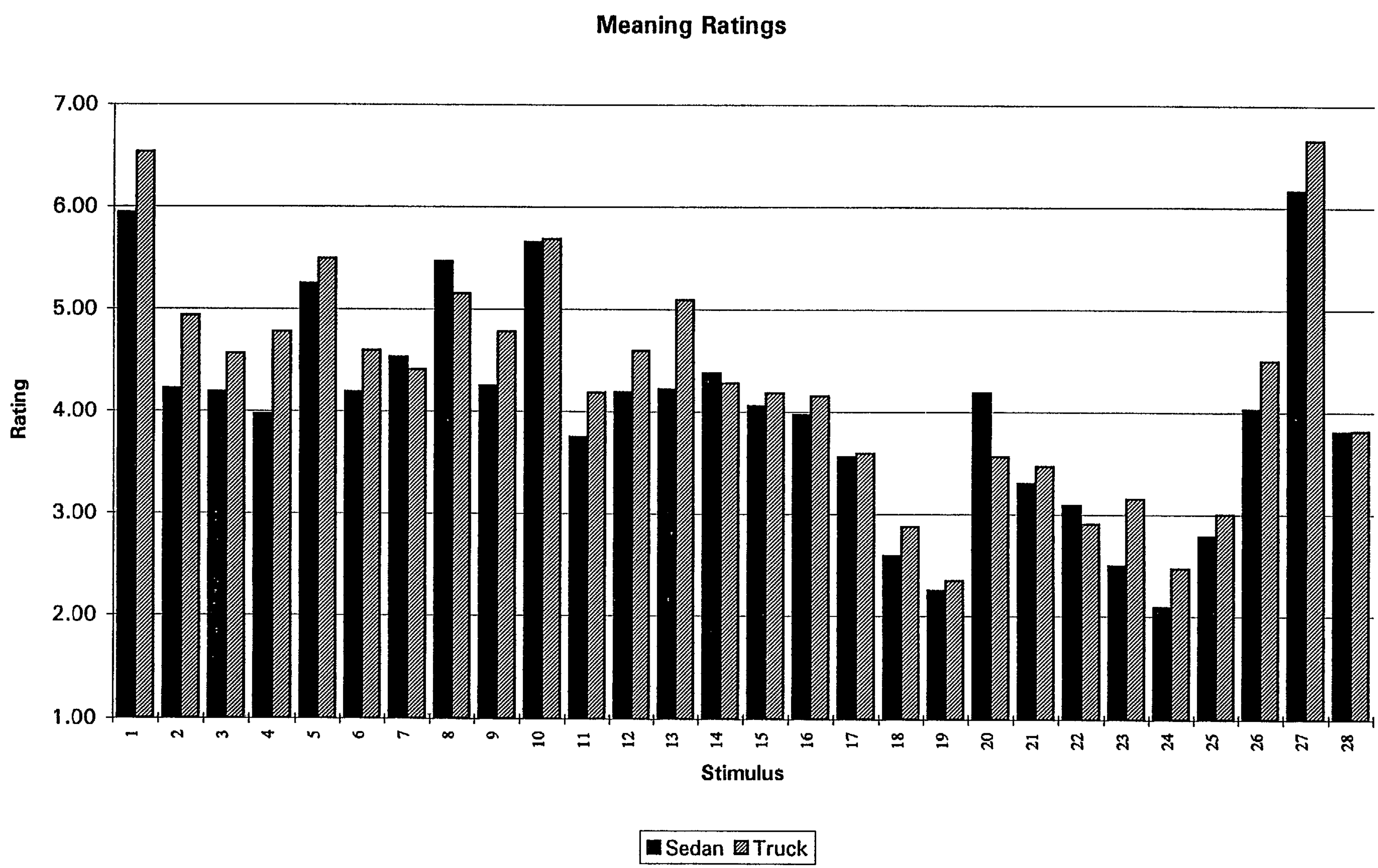
APPENDIX I: MAE RATINGS - BAR GRAPHS FOR EACH ATTRIBUTE


Noticeability Ratings
Rating
7.00
6.00
5.00
4.00
3.00
2.00
1.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Stimulus
Sedan
Truck


Discrimination Ratings
7.00
6.00
5.00
4.00
3.00
2.00
1.00
Rating
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
Stimulus
Sedan
Truck

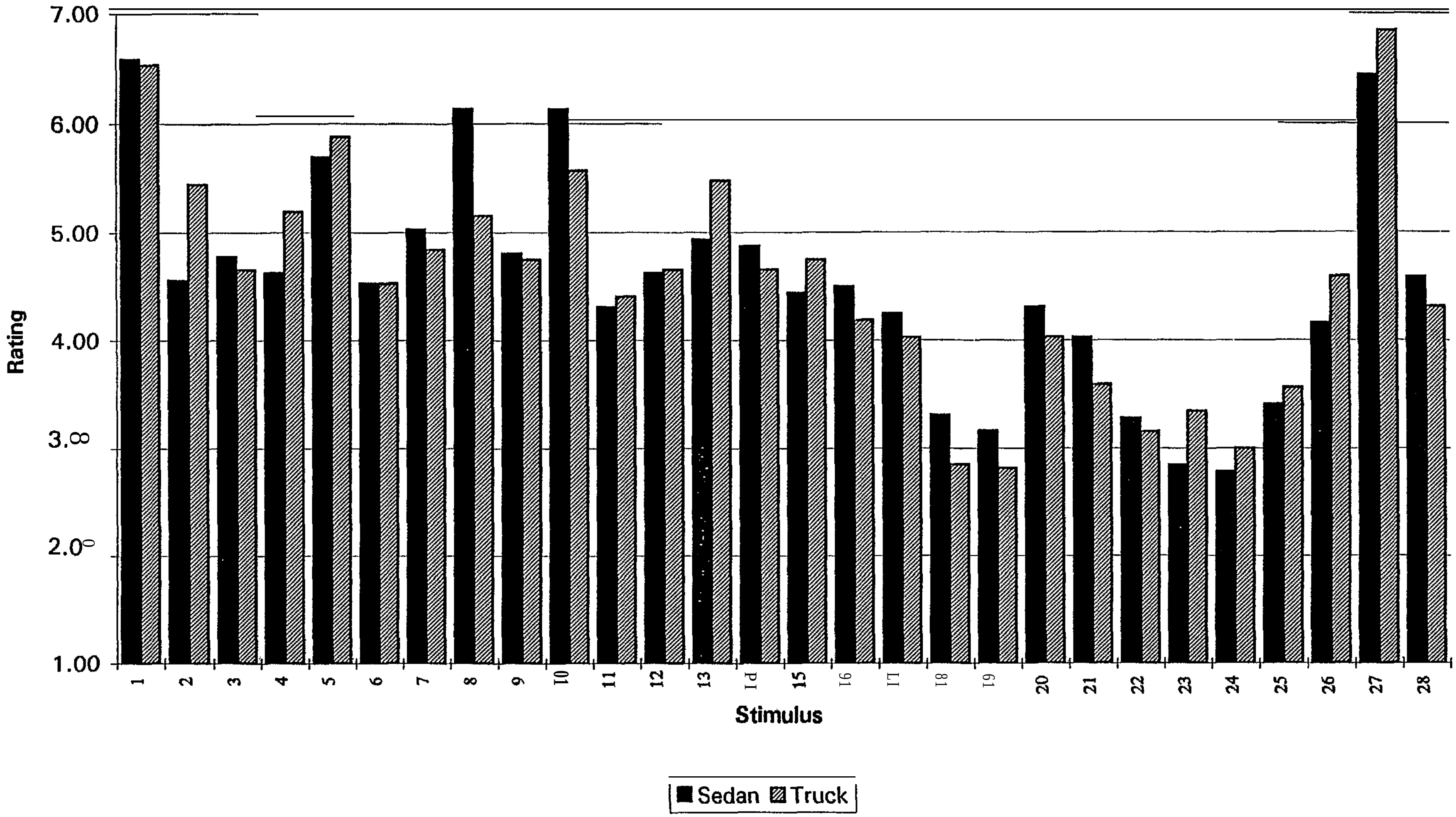
Meaning Ratings



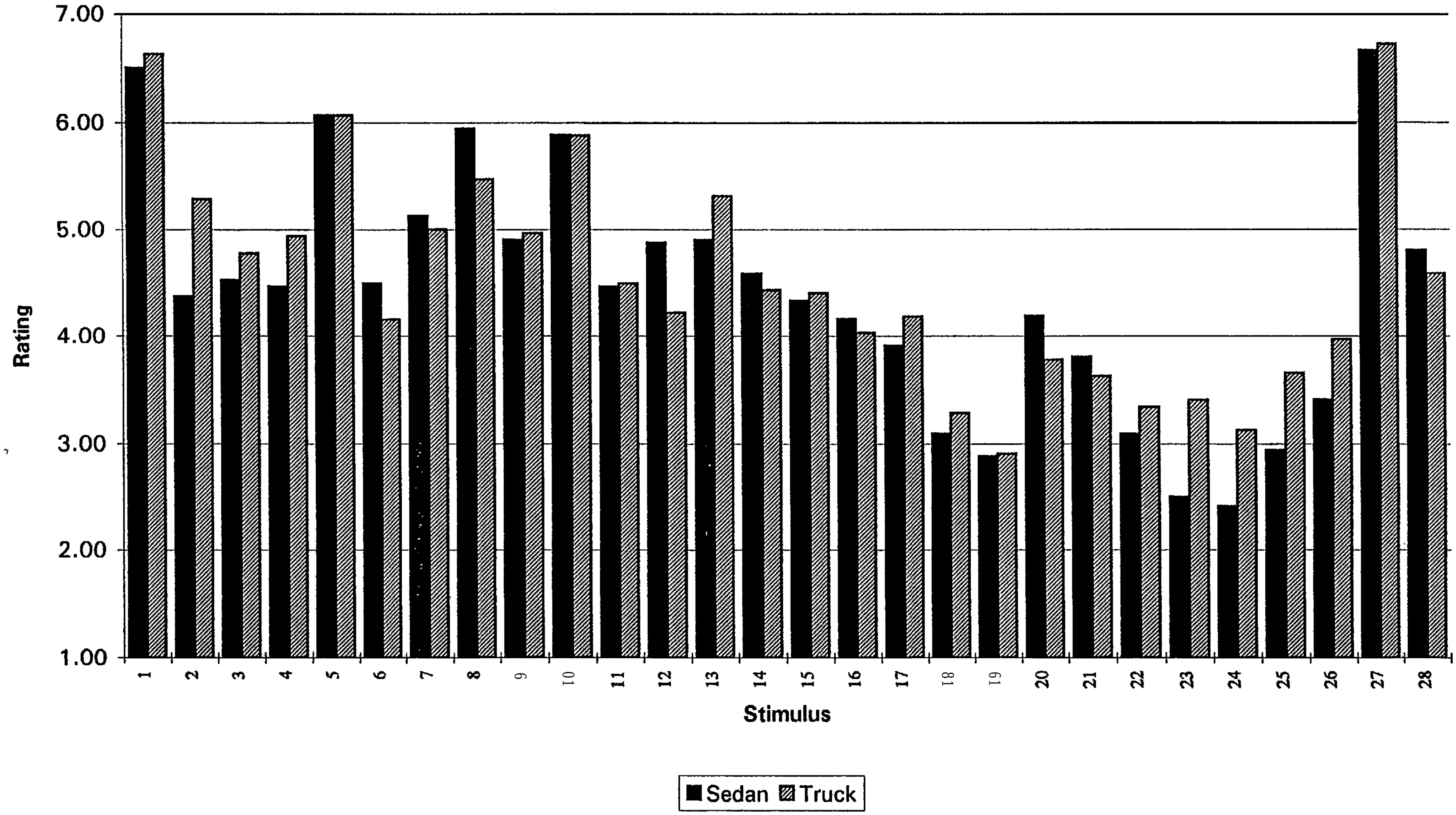


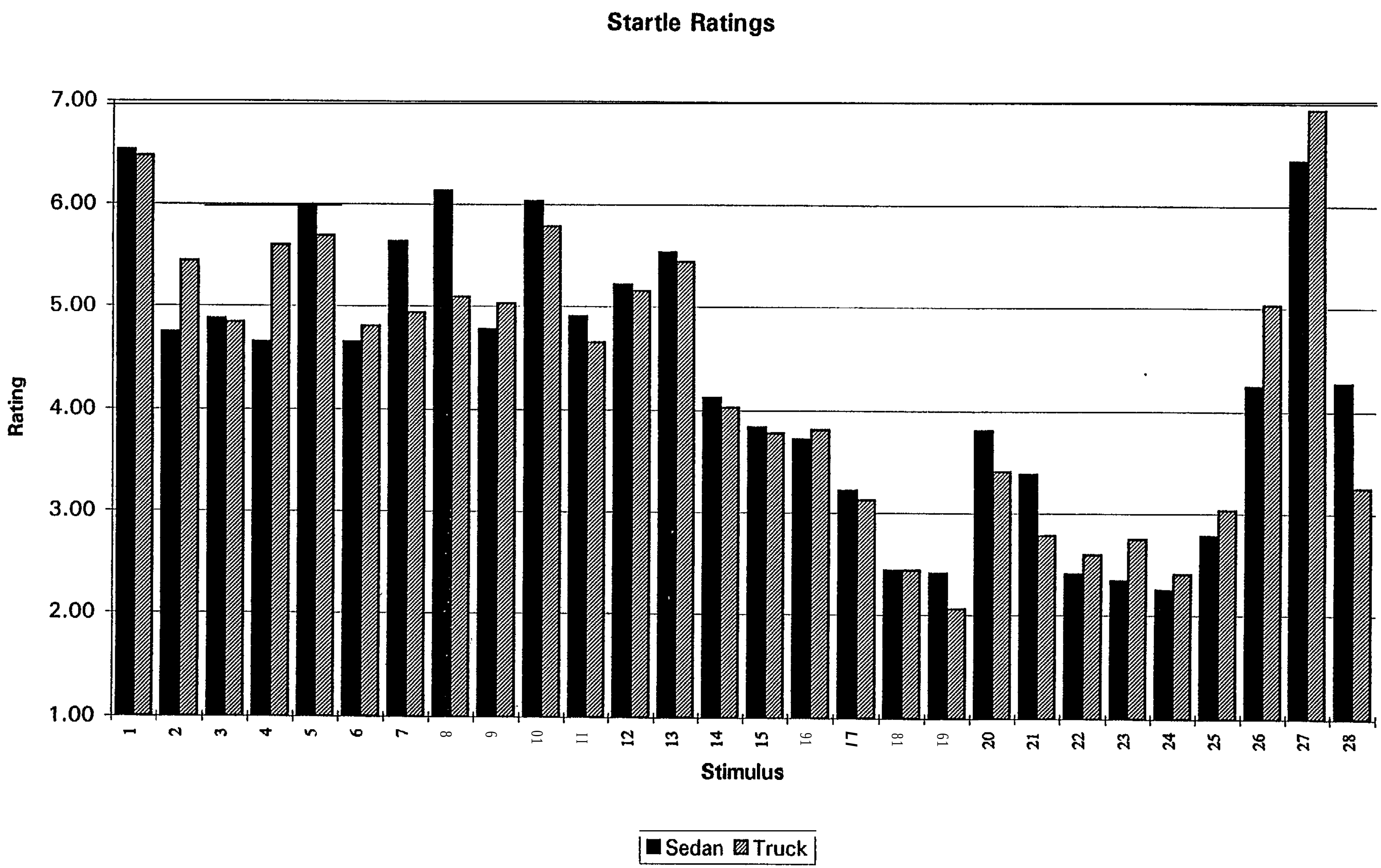
Meaning Ratings
7.00
6.00
5.00
4.00
3.00
2.00
1.00
Rating
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Stimulus
Sedan
Truck

Natural Response Ratings



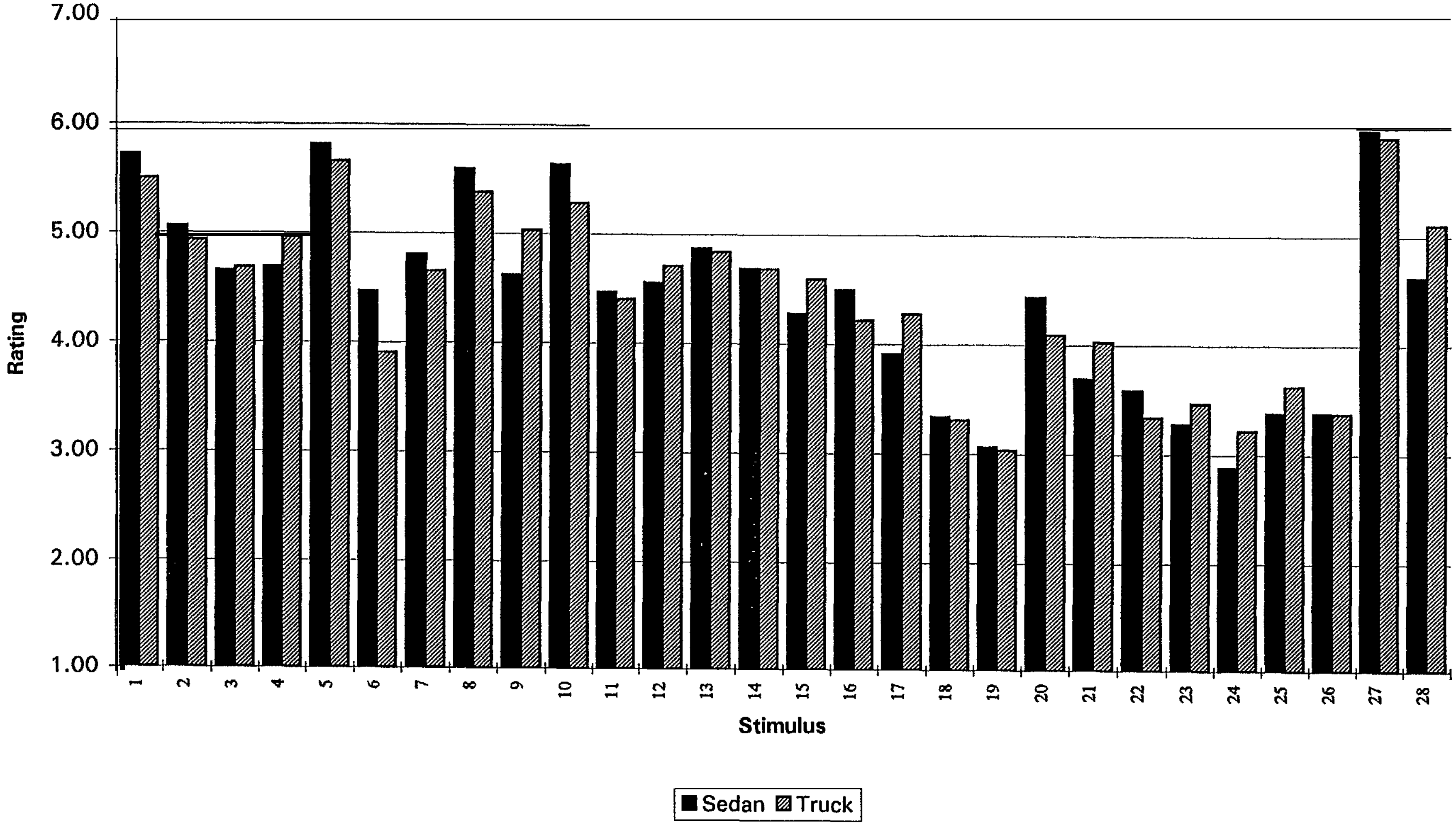
Emergency Ratings

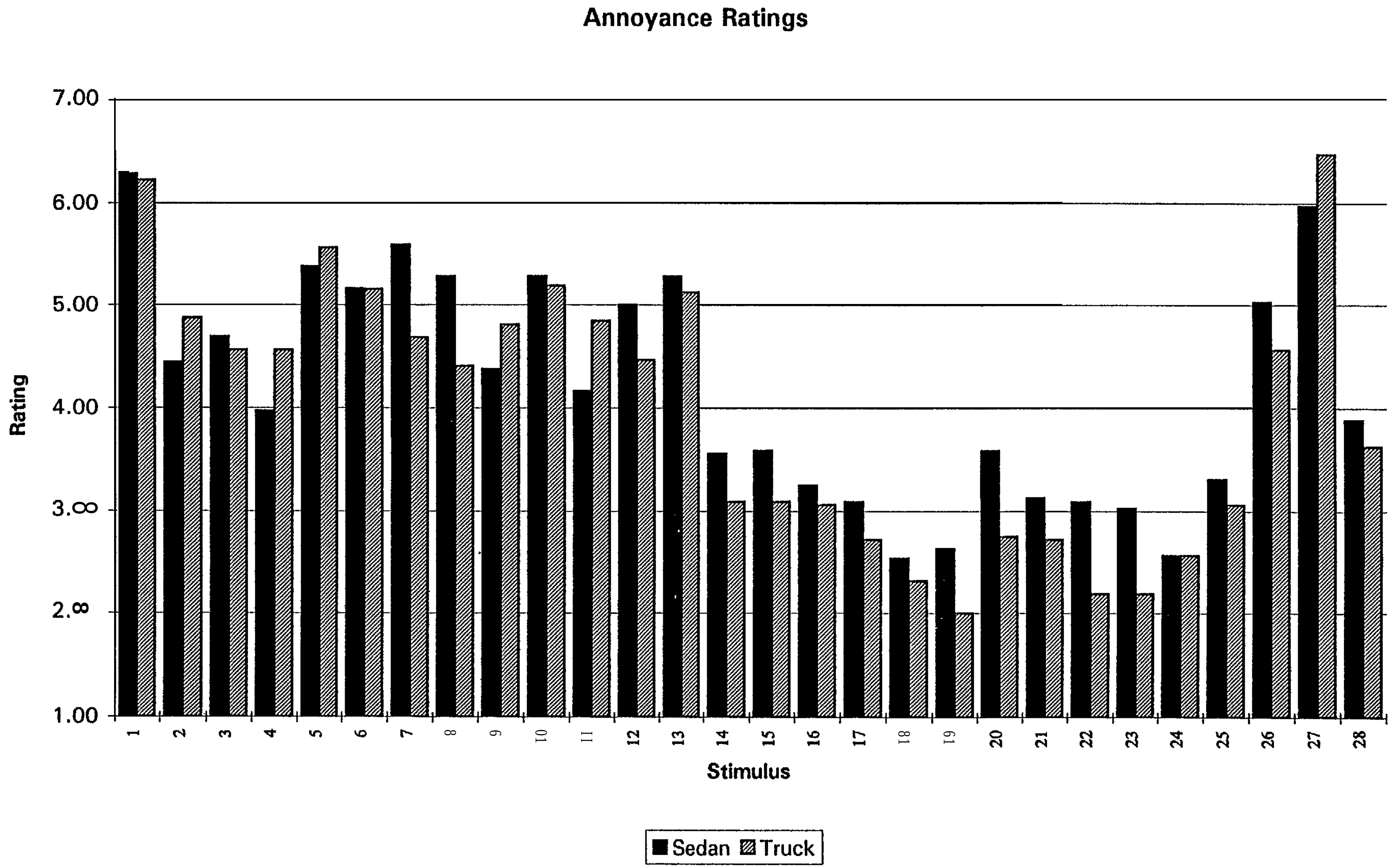


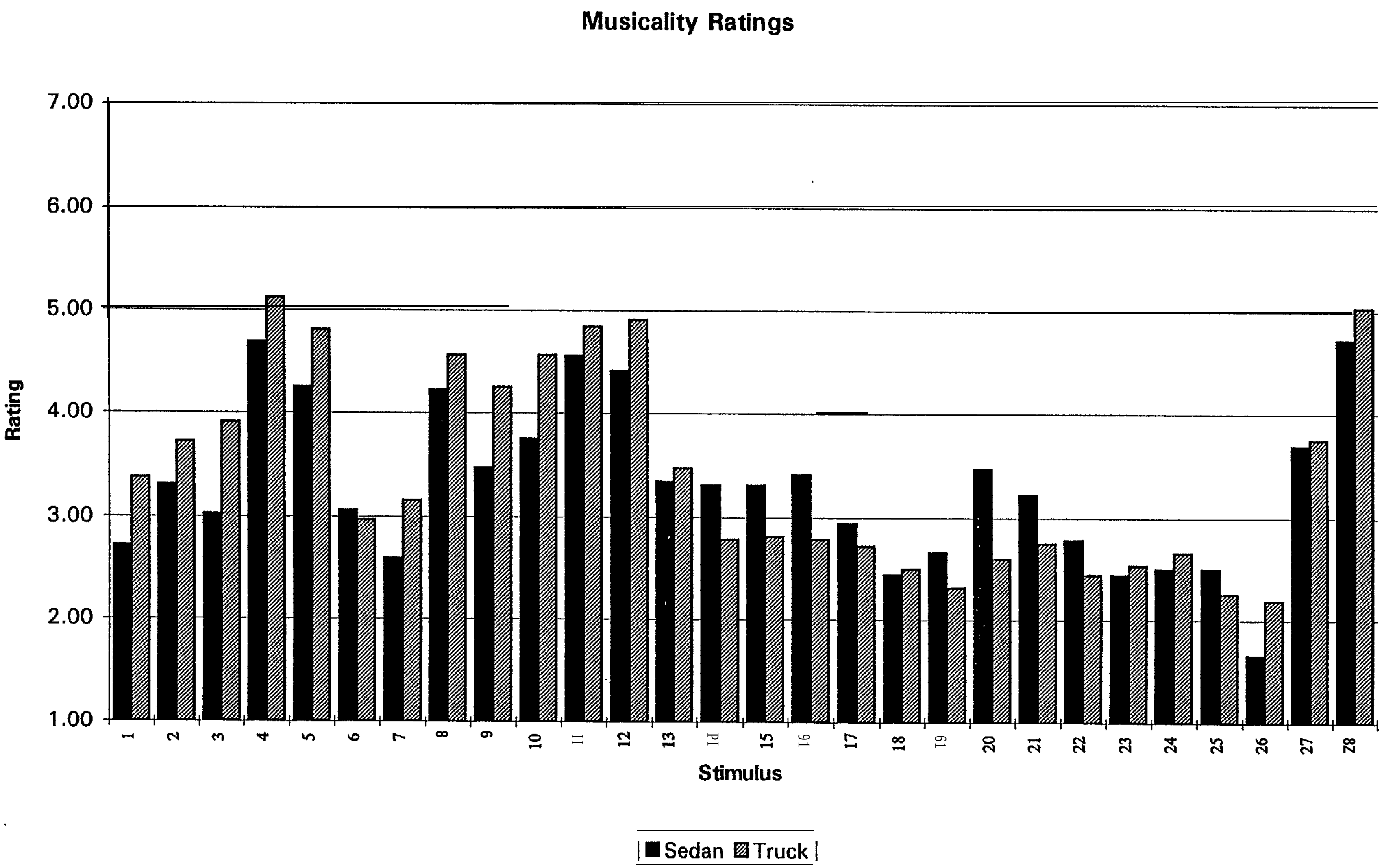


Startle Ratings
7.00
6.00
5.00
4.00
3.00
2.00
1.00
Rating
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
Stimulus
Sedan
Truck

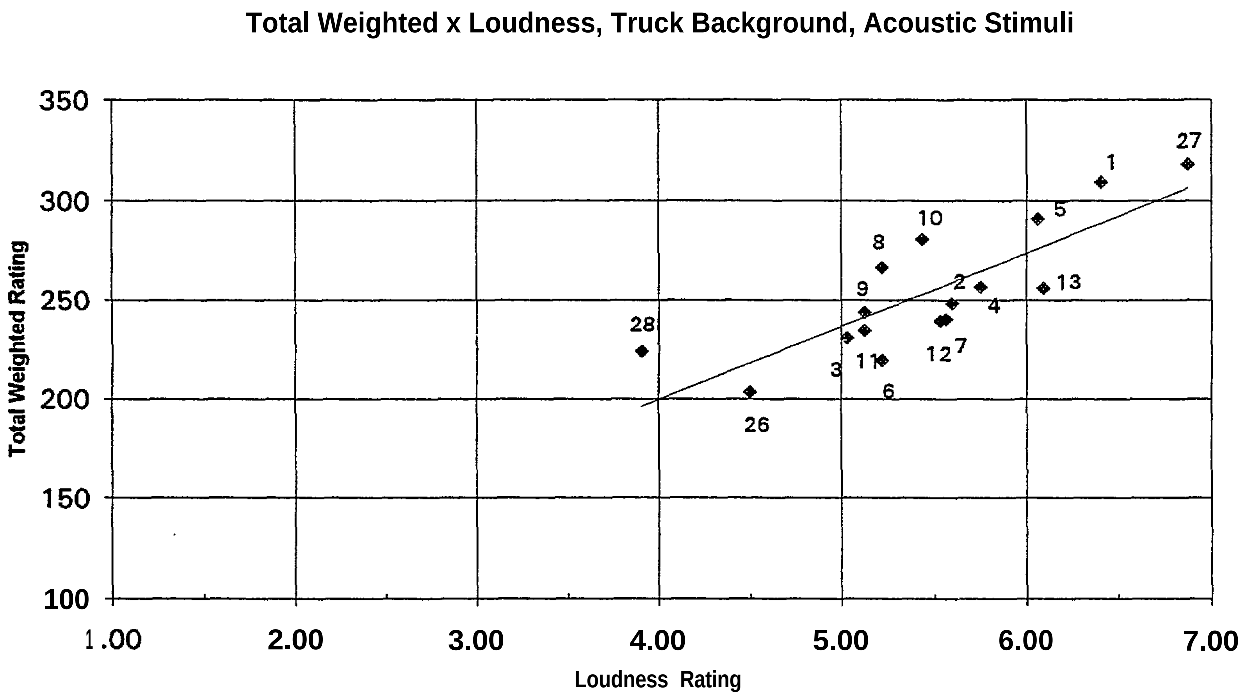
Appropriateness Ratings

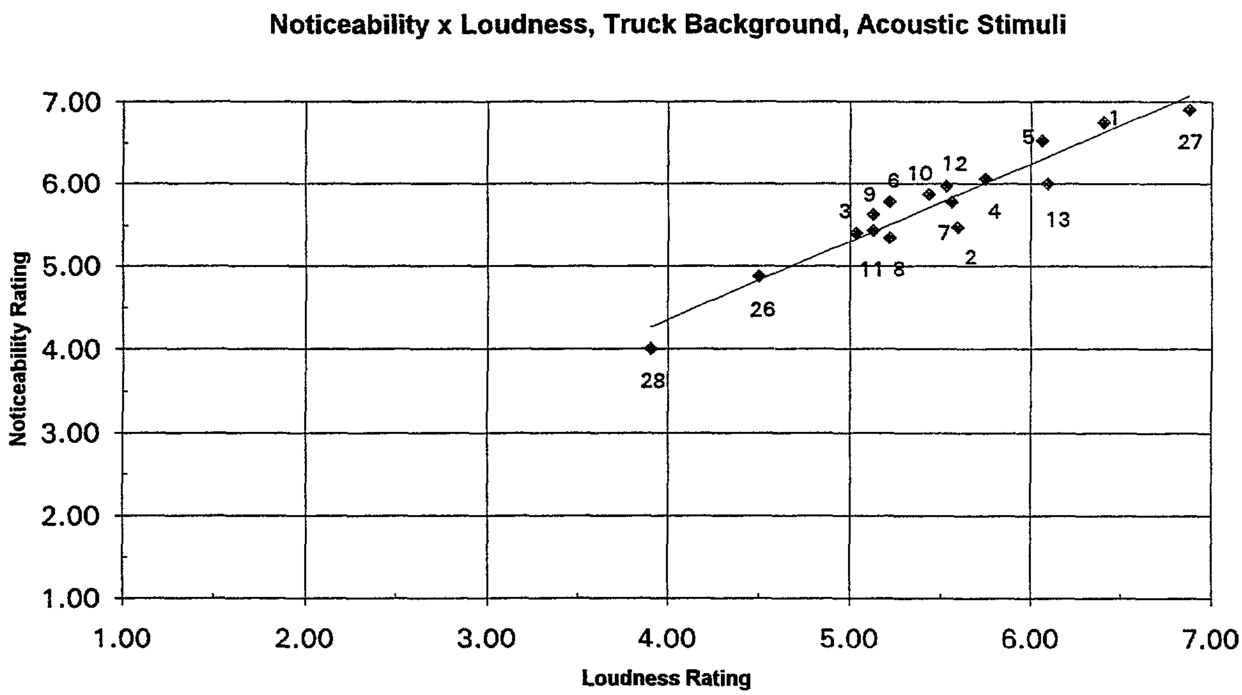



Annoyance Ratings
7.00
6.00
5.00
4.00
3.00
2.00
1.00
Rating
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Stimulus
Sedan
Truck

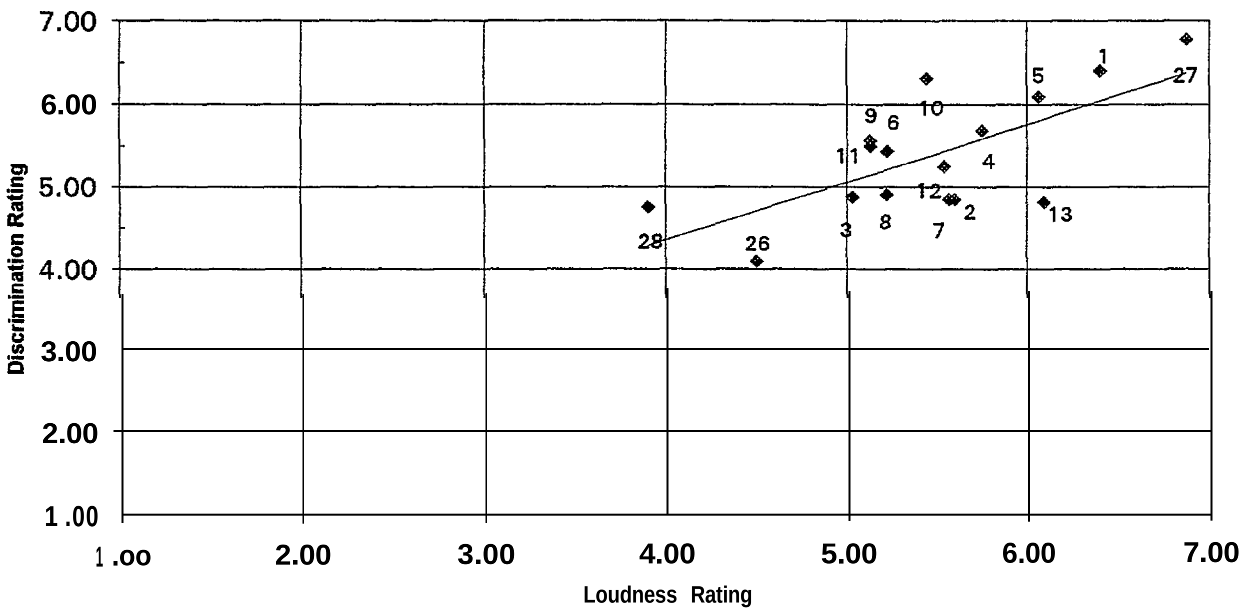

Musicality Ratings
7.00
6.00
5.00
4.00
3.00
2.00
1.00
Rating
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Stimulus
Sedan
Truck

APPENDIX J: SCATTER PLOTS FOR ACOUSTIC WARNINGS IN TRUCK BACKGROUND NOISE CONDITION

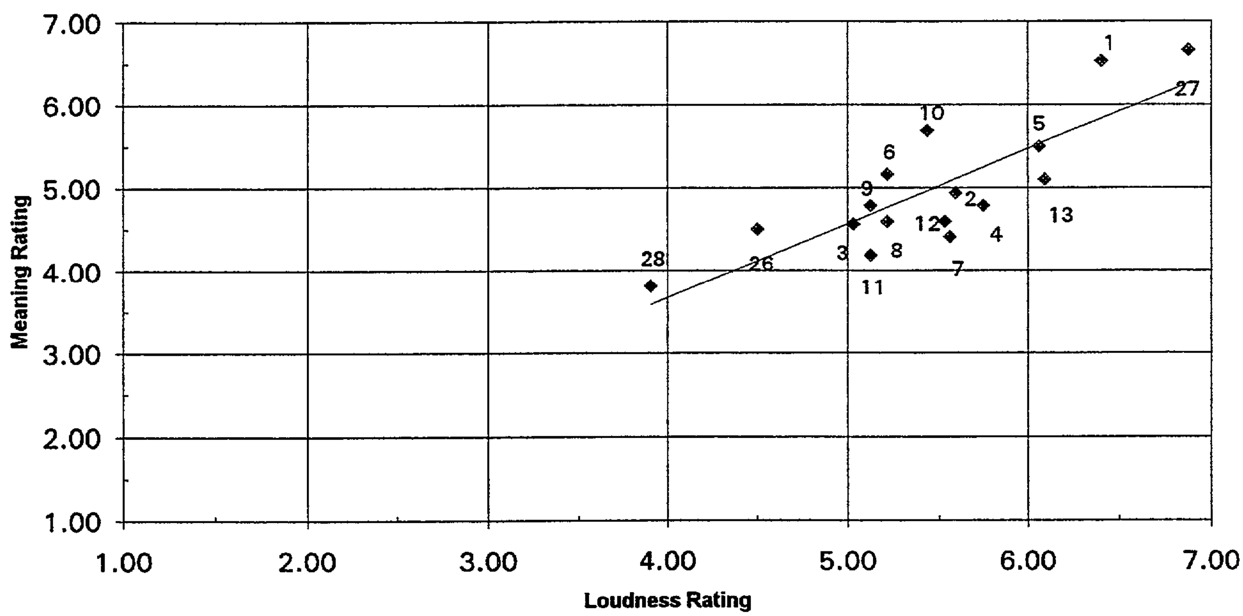

Total Weighted x Loudness, Truck Background, Acoustic Stimuli
Total Weighted Rating
Loudness Rating
350
300
250
200
150
100
1.00
2.00
3.00
4.00
5.00
6.00
7.00
27
1
5
10
8
9
2
4
13
28
3
11
12
7
6
26


Noticeability x Loudness, Truck Background, Acoustic Stimuli
Noticeability Rating
Loudness Rating
7.00
6.00
5.00
4.00
3.00
2.00
1.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
5
27
12
10
6
9
3
4
13
7
2
11
8
26
28

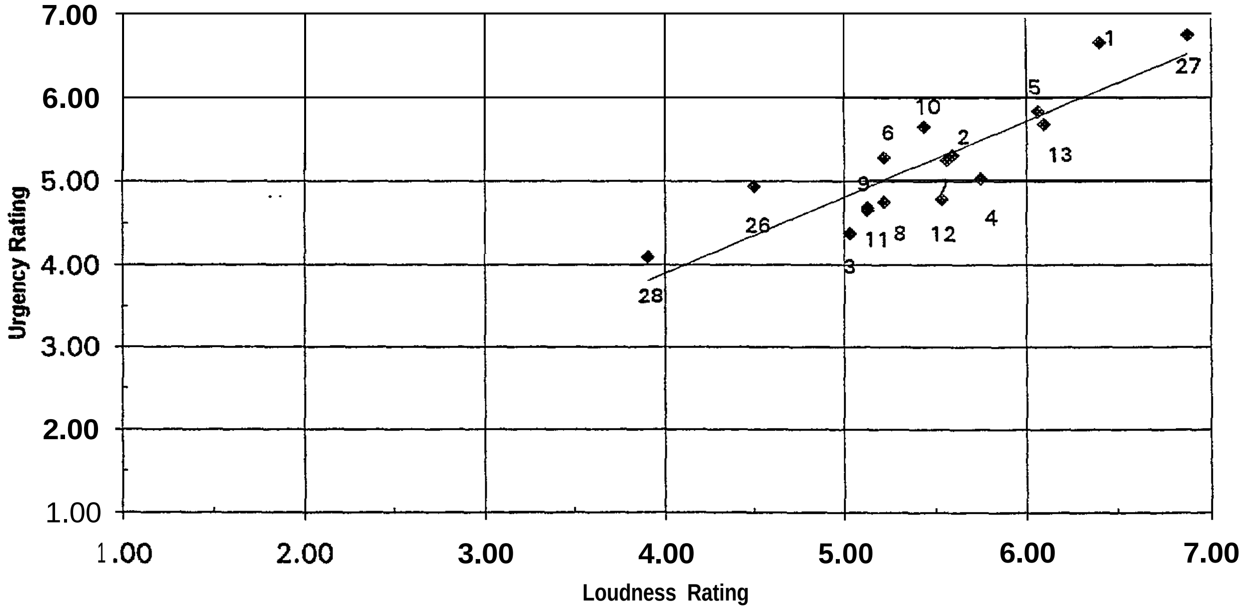
Discrimination x Loudness, Truck Background, Acoustic Stimuli



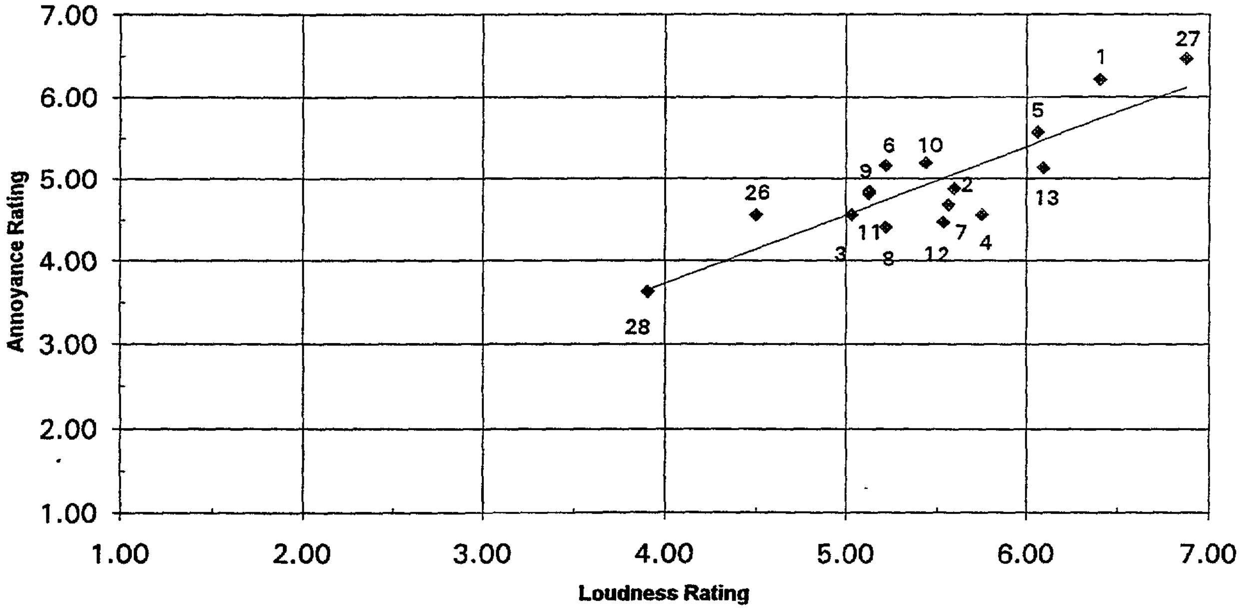
Meaning x Loudness, Truck Background, Acoustic Stimuli



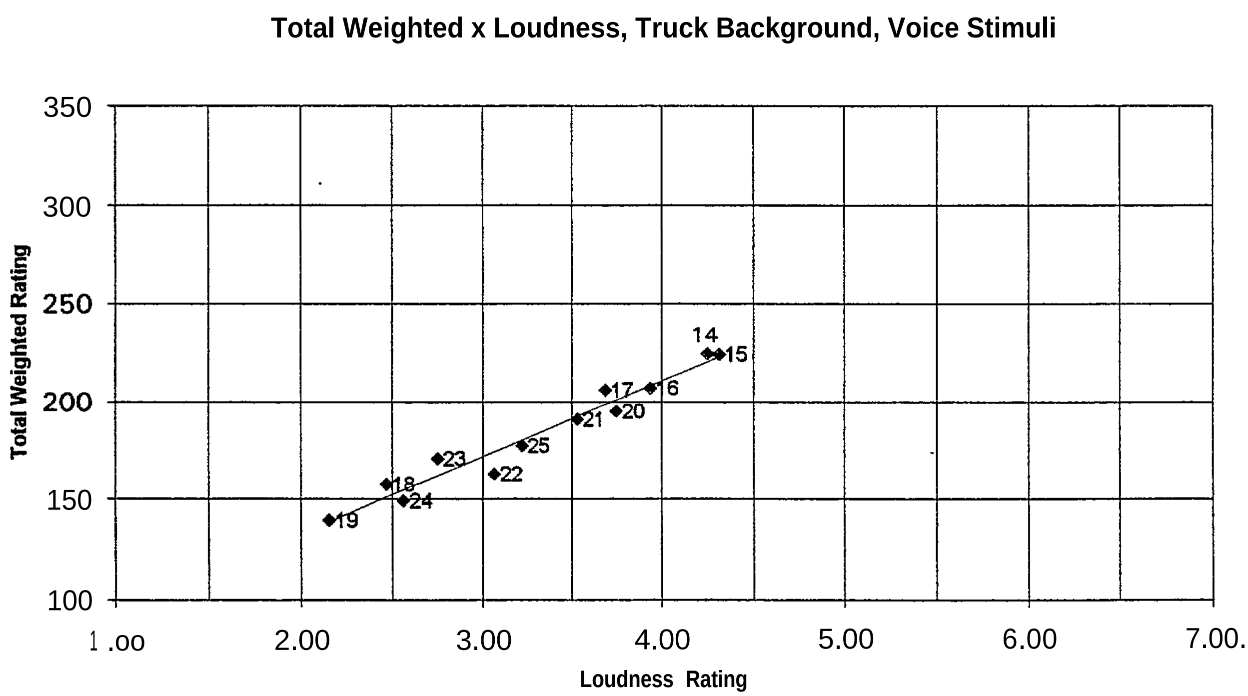
Urgency x Loudness, Truck Background, Acoustic Stimuli



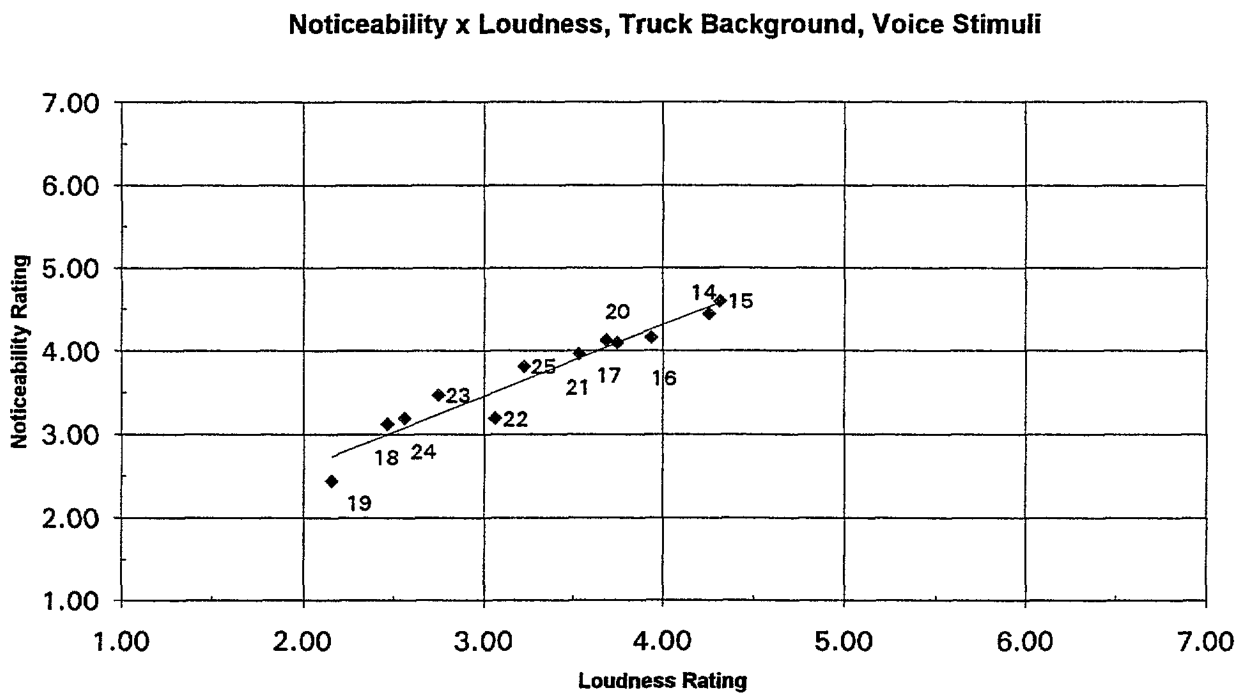
Annoyance x Loudness, Truck Background, Acoustic Stimuli



APPENDIX K: SCATTER PLOTS FOR VOICE WARNINGS IN TRUCK BACKGROUND NOISE CONDITION

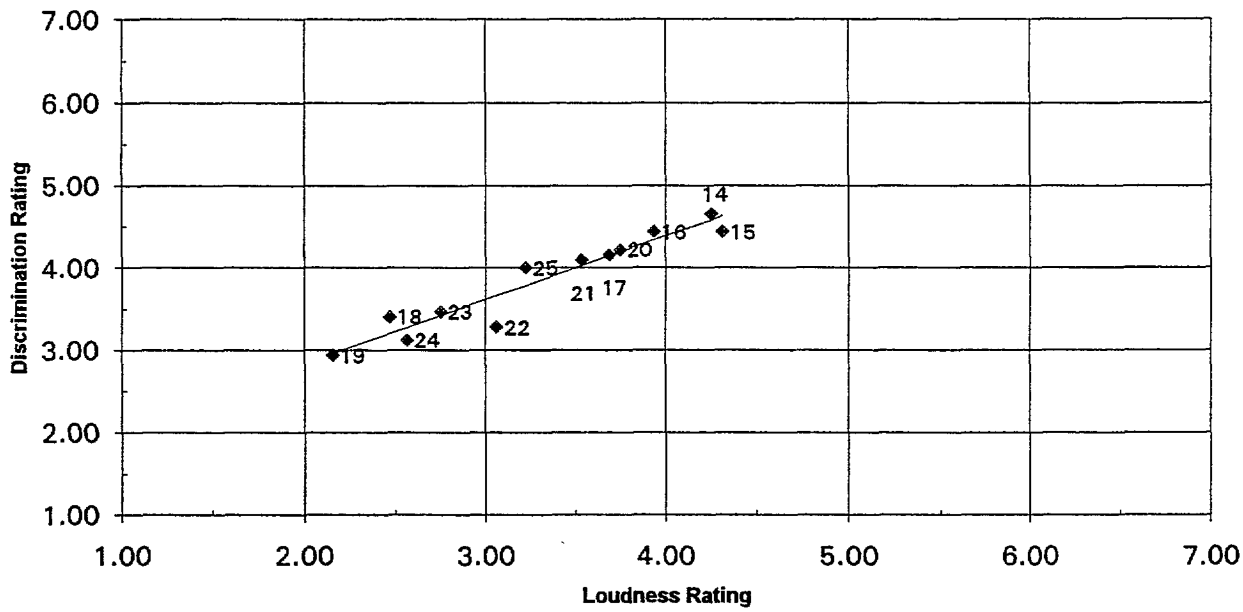


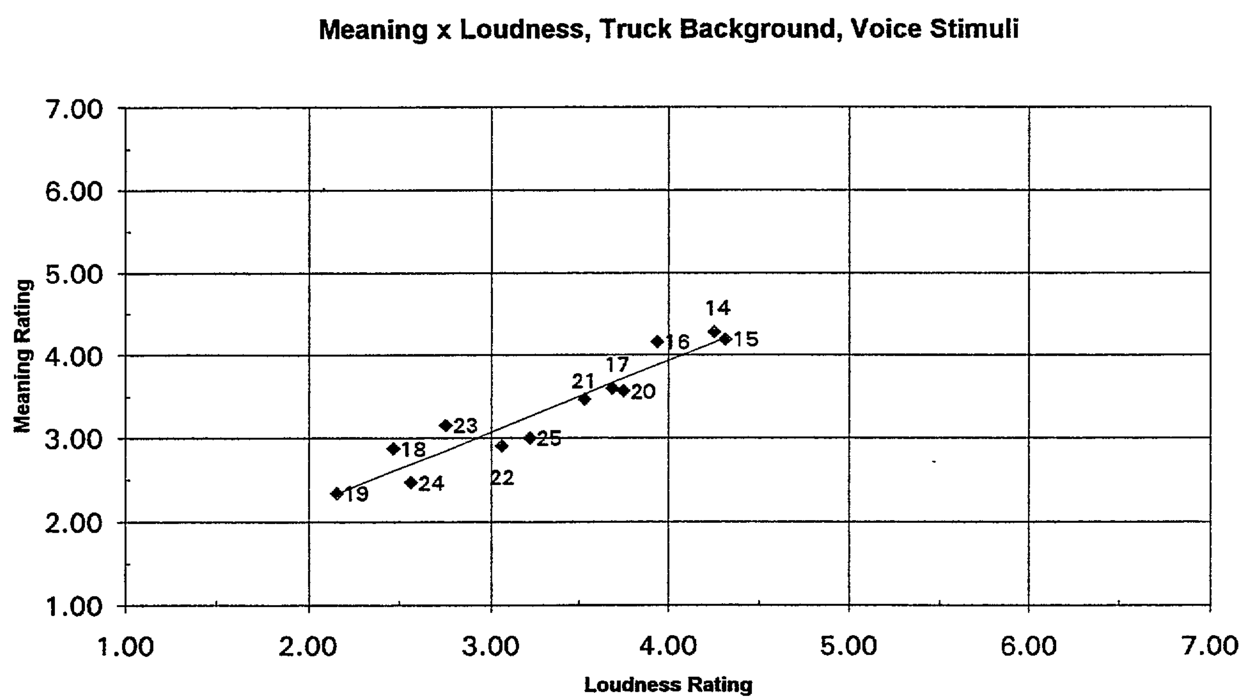
Total Weighted x Loudness, Truck Background, Voice Stimuli
350
300
250
200
150
100
Total Weighted Rating
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Loudness Rating
14
15
16
17
20
21
25
23
22
18
24
19



Noticeability x Loudness, Truck Background, Voice Stimuli
Noticeability Rating
Loudness Rating
7.00
6.00
5.00
4.00
3.00
2.00
1.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
14
15
20
25
21
17
16
23
22
18
24
19

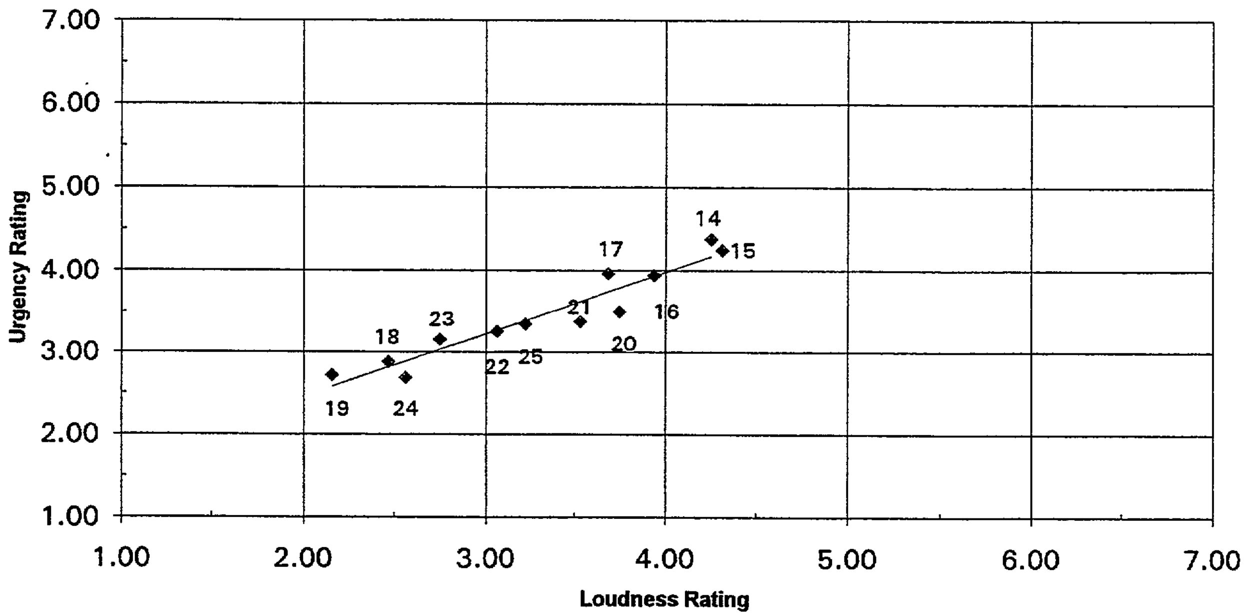
Discrimination x Loudness, Truck Background, Voice Stimuli





Meaning x Loudness, Truck Background, Voice Stimuli
7.00
6.00
5.00
4.00
3.00
2.00
1.00
Meaning Rating
14
16
15
17
21
20
23
25
18
22
24
19
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Loudness Rating

Urgency x Loudness, Truck Background, Voice Stimuli



Annoyance x Loudness, Truck Background, Voice Stimuli