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**Mapping of Psychoacoustic Parameters to the
Perceived Urgency of Auditory Warning Signals**

by

Kathryn L. Momtahan, B.A.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of

(Master of Arts)

Department of Psychology

Carleton University

Ottawa, Ontario

August 3, 1990

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The undersigned hereby recommend to
the Faculty of Graduate Studies and Research
acceptance of the thesis

MAPPING OF PSYCHOACOUSTIC PARAMETERS TO THE
PERCEIVED URGENCY OF AUDITORY WARNING SIGNALS

submitted by
Kathryn L. Momtahan, B.A.

in partial fulfilment of the requirements
for the degree of Master of Arts

Thesis Supervisor

Chair, Department of Psychology

Carleton University

ABSTRACT

Two experiments were conducted in order to investigate the effects of varying acoustic parameters on subjects' ratings of perceived urgency. Subjects in Experiment 1 were presented with two 3-second windows of sound pulses and asked to judge which of the two sounded more urgent. The sound parameters investigated were interpulse interval length, pulse length, amplitude modulation, number of harmonics, spectral shape, fundamental frequency, frequency modulation, frequency glides, envelope shape, and pitch steps. Sound parameters from Experiment 1 most reliably differentiated in terms of their perceived urgency were incorporated into Experiment 2 where the urgent and less urgent levels of six sound parameters were combined. The sound parameters investigated in Experiment 2 were interpulse interval length, number of harmonics, spectral shape, fundamental frequency, frequency glide, and loudness. In Experiment 2, the main effects of interpulse interval length, number of harmonics, spectral shape, frequency glide, and loudness were significant ($p < .0001$) but the main effect of fundamental frequency was not. Further research is necessary in order to discover the ways in which fundamental frequency affects ratings of perceived urgency when combined with some of the other sound parameters tested such as the number of harmonics and frequency glide.

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Table of Contents

	Page
Abstract	iii
Acknowledgements	iv
Table of Contents	v
List of Tables	vii
List of Figures	viii
 Introduction	 1
Human factors recommendations for the design of auditory alarms	3
Advantages of learning a standard set of auditory alarms	6
Description of the set of auditory alarms developed by Patterson, Shailer, Lower, and Wheeler (1986) for Medical Equipment in Intensive Care Areas and Operating Theatres	7
Temporal coding of auditory warning signals	8
Using sounds of differing pitch contours	9
Description of the set of auditory alarms developed by Stanford, McIntyre, and Hogan (1985) for anaesthesia monitoring equipment	10
General overview and rationale for choosing the parameters incorporated into the warning signals to be tested	11
Length of time between tone bursts	11
Tone (pulse) duration	12
Advantage of variable dimension coding	14
Acoustic parameters varied by J. Edworthy and her colleagues and their effects on perceived urgency ratings	14
 Experiment 1	
Introduction	17
The parameters chosen by Edworthy et al. that correspond to the parameters chosen for Experiment 1	18
Rationale for choosing amplitude and frequency modulation as acoustic parameters to vary	19
Choice of amplitude and frequency modulation rates	19
Rationale for investigating spectral shape and number of harmonics	20

Method	21
Results	31
Discussion	36
Experiment 2	
Introduction	38
Method	39
Results	40
Discussion	44
General Discussion	45
References	50
Appendix A: Description of hardware and software used for thesis experiments	
Appendix B: Software Programs to Run Experiment 1	
Appendix C: Software Programs to Run Experiment 2	
Appendix D: Graphs of Interactions and Tables of Significant Simple Main Effects	
Appendix E: Graphs comparing levels of the harmonics programmed into MITSYN and the levels measured 1 meter from the speaker	

List of Tables

Table	Page
1. Significant main effects and interaction effects of variables in Experiment 2	41
2. Differences between the means of the main effects of Experiment 2	44

List of Figures

Figure		Page
1.	Mean urgency ratings of the two levels of the six sound parameters with the two levels (low urgency and high urgency) on the abscissa	42
2.	Mean urgency ratings of the two levels of the six sound parameters with the sound parameters on the abscissa	43

Introduction

The auditory alarm is a common feature found on equipment in operating rooms, recovery rooms, intensive and coronary care units, and emergency departments of hospitals. The variety of equipment furnished with auditory alarms include anaesthesia delivery machines, ventilators, cardiac monitors, pulse oximeters, non-invasive blood-pressure machines, intravenous infusion pumps, intracranial pressure monitors, warming and cooling units, and other more specialized equipment such as dialysis machines, aortic balloon pumps, and electronic tourniquets. The patient-related equipment found in any given critical care unit is usually purchased over a number of years and from a variety of manufacturers.

There are currently no standards for the design of auditory alarms on medical equipment and so the type of auditory alarms fitted into each piece of equipment is left up to the manufacturer. Manufacturers often insert auditory alarms into their equipment without knowledge of the compatibility with the auditory alarms of other medical equipment manufacturers. The lack of standards for these alarms as well as a lack of consumer pressure, has led to a situation in the hospital setting which is ergonomically unsound.

The various problems associated with the lack of standards as well as a lack of adequate research into the design of these auditory alarms have been well enough documented to argue for change. McIntyre and Stanford (1985) found that some of the alarms in the operating room could be masked by surgical equipment noise. The large number of alarms in any given setting (which can be as high as thirty or more) has been a source of concern (McIntyre, 1985; Samuels, 1986). Momtahan and Tansley (1989) found that recovery room nurses were able to identify a mean of only 8 of the 21 auditory alarms found in their recovery room by their acoustic properties. Anaesthetists were only able to identify a mean of 5 of the 21 auditory alarms found in their operating theatres. Fourier transform and temporal analyses of these alarms reveal that many of the alarms are similar

enough in pitch to be confused with one another and also that they are all either continuously sounding alarms or that they have regularly repeating patterns of on-off.

Another problem with the existing auditory alarms on medical equipment is that there is no urgency-mapping of the acoustic properties of alarm sounds to the medical urgency of the alarm. Momtahan and Tansley (1989) had 40 naive listeners rate existing medical alarms on their perceived urgency. These results were compared to the ranking of the urgency of the medical condition that the alarms were signalling as judged by a sample of nurses and anaesthetists. In the case of the operating room alarms, no correlation was found between perceived urgency of the alarm and the medical urgency of the condition being signalled by the alarm. There was a statistically significant negative correlation in the case of the recovery room alarms. A similar lack of mapping of acoustic urgency to medical urgency of alarms in the operating room was reported by Finley and Cohen (1989).

The mapping of perceived urgency of acoustic parameters to the intended urgency of an alarm has not been explored in the research literature until very recently (Edworthy, Loxley, Geelhoed, and Dennis, 1989; Hellier and Edworthy, 1989). The urgency of the alarm's sound is an important aspect in the design of auditory alarms for medical equipment (or for other alarm systems such as those in factories or the cockpits of airplanes). However, mapping of perceived urgency to the urgency of the condition being alarmed is only one aspect of the acoustic design. The other components that need to be included in the design are discussed first, followed by a discussion of two sets of auditory alarms designed for use on medical equipment that have appeared in the literature. The research conducted by J. Edworthy and her associates will be reviewed and referred to when discussing the design of the experiment being proposed.

Human Factors Recommendations for the Design of Auditory Alarms

The following guidelines specifying conditions under which the use of auditory signals are appropriate are summarized in Deatherage (1972). This table is reproduced in Sorkin (1987) and very similar recommendations are to be found in Sanders and McCormick (1986) and Woodson (1981).

When to Use the Auditory or Visual Form of Presentation

Use auditory presentation if:	Use visual presentation if:
1. The message is simple.	1. The message is complex.
2. The message is short.	2. The message is long.
3. The message will not be referred to later.	3. The message will be referred to later.
4. The message deals with events in time.	4. The message deals with location in space.
5. The message calls for immediate action.	5. The message does not call for immediate action.
6. The visual system of the person is overburdened.	6. The auditory system of the person is overburdened.
7. The receiving location is too bright or dark-adaptation integrity is necessary.	7. The receiving location is too noisy.
8. The person's job requires him to move about continuously.	8. The person's job allows him to remain in one position.

Except for condition number 7, the hospital environment matches all the conditions for which auditory alarms are recommended and matches the conditions for both auditory and visual signals listed under recommendation number four. The receiving location is not typically too bright for a visual signal nor is dark-adaptation integrity necessary, and although the receiving location is typically noisy, the frequency band in which the noise occurs can be avoided when designing auditory signals. Alarm activation in the hospital typically deals with location in space as well as events in time which is why, for each auditory signal, there is usually a visual signal to accompany it in order to locate the message in space.

Concerning the specific design of auditory alarms, the following table of recommendations is found in Sorkin (1987), page 558 and is based on recommendations made by Patterson (1982).

Spectral Considerations for Auditory Warning and Alarm Signals

1. The pitch of warning sounds should be between 150 and 1000 Hz.
 2. Signals should have at least four prominent frequency components. As a consequence:
 - a. The chance of masking by other sounds is minimized.
 - b. There is a minimum of changes to pitch and sound quality under masking conditions.
 - c. The number of different distinctive signal codes that may be generated is maximized.
 3. Signals with harmonically regular frequency components should be used rather than inharmonic spectra.
 - a. Lower-priority warning signals should have most of their energy in the first five harmonics.
 - b. Higher-priority, immediate action signals should have relatively more energy in harmonics 6 through 10.
 - c. High-priority signals can be made very distinctive by incorporating a small number of additional inharmonic components.
 4. The prominent frequency components for signals should be in the range from 1000 to 4000 Hz.. At least four of the first 10 harmonics should be prominent.
 5. Rapid glides (100 msec) in the fundamental frequency of a signal (providing that the above constraints are not violated) can be an effective way to signal urgency and command listener attention.
-

Patterson's reasoning for the first two recommendations is as follows:

A warning sound must contain at least four harmonics if it is to produce a reliable residue pitch rather than several high pitches corresponding to individual component frequencies. Furthermore, four of the first ten harmonics should be prominent to ensure a strong pitch and to provide for sufficient distinctiveness among the members of the warning set. Sets of exclusively high harmonics produce a thin, buzzy sound with a relatively weak pitch. To avoid masking, the four prominent components should fall in the appropriate frequency region (1.0 - 4.0 kHz).

This implies that the upper bound for the pitch of warning sounds is 1000 Hz; this is the highest fundamental for which four harmonics (numbers 1 - 4) can be generated in the region below the upper bound for component frequencies (4.0 kHz). Similarly it implies that the lower bound for the pitch of warning sounds is 143 Hz; this is the lowest fundamental for which four components (numbers 7 - 10) can be generated with the lowest frequency (7×143 Hz) above the lower bound of the appropriate range for component frequencies (1.0 kHz). (p. 37)

The strength of this argument is based upon the phenomenon known as residue (or periodicity) pitch. Residue pitch refers to the perception of a tone whose frequency corresponds to the fundamental frequency of the harmonics even if there is no sound energy at the fundamental frequency; this is sometimes referred to as the 'phenomenon of the missing fundamental' (Moore, 1982, p. 123). Licklider (1954) demonstrated that residue pitch (the low-pitched sound of the fundamental) continues to be perceived by subjects even when the low-frequency channels are saturated with low-frequency masking noise: Although the fundamental frequency will be heard regardless of which harmonics are present, the timbre of the sound will depend on which harmonics are present as well as the strength of the harmonics. Moore (1982) describes timbre as "that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar" (p. 288).

One of the advantages of including frequency components that are below 1 kHz is that sound localization using interaural time difference cues is best below 1 kHz and sounds of lower frequencies are more easily perceived than higher frequency sounds when there are partitions or other obstacles (Sandel, Teas, Feddersen, & Jeffress, 1955; Stevens & Newman, 1936). Sound localization using intensity difference cues is best for frequencies above 4 kHz. Although sound localization cues are best for frequencies below 1 kHz or above 4 kHz, humans are most sensitive (have lower thresholds) to sounds between 1 kHz and 4 kHz (Fletcher & Munson, 1933; Sivian & White, 1933). This is the reason why it is desirable to incorporate harmonics between 1 kHz and 4 kHz into the auditory signal.

Advantage of Learning a Standard Set of Auditory Alarms

The most obvious advantage of having a standard set of auditory alarms for any system is that the number of alarms designed for the system can be kept to a level which can be learned and retained by the people responsible for monitoring the alarms. Patterson and Milroy (1980) investigated the learning and retention of aircraft warning signals. They found that subjects were able to learn from four to six auditory warnings quickly (within a few trials) but that when the number of alarms exceeded six, that learning slowed dramatically and the signals were often confused. Patterson's 1982 recommendation is that there be no more than four to nine auditory warnings in any one setting. Sanders and McCormick (1987) recommend five. In a survey of the use of auditory alarms by Canadian anaesthetists, McIntyre (1985) found that the most popular number of individually recognizable auditory alarms that the anaesthetists felt they could cope with was five. These findings and recommendations are consistent with the well-known limits to human information processing. G. A. Miller originally described the limit of human information processing as it relates to absolute perceptual judgments in what has since become a classic paper in the area of psychology. He describes this limit as being 7 plus or minus two items or in information processing jargon, approximately 3 bits of information (i.e. 8 equally likely alternatives).

The second advantage to having a defined set of auditory alarms is that once the persons responsible for monitoring the alarms have learned to recognize and associate a meaning to these alarms, their detection thresholds for those sounds will decrease so that the alarms are more likely to be detected. Scharf, Quigley, Aoki, Peachey, and Reeves (1987) used the probe-signal method of Greenberg and Larkin's (1968) to determine the percentage of trials in which subjects detected a soft, expected (learned) sound as compared with an unexpected sound under a two-interval, forced choice condition. They found that pure tones at or near the expected frequency were detected in about 90% of the trials as compared to tones that were more than one-half critical band away. These tones were

detected 50% of the time (i.e. near chance). These results are very similar to those obtained by Greenberg & Larkin (1968).

Scharf et al. (1987) extended these results to include complex signals. Complex sounds were similarly more readily detected if they were inside the same critical band of the expected frequency than if they were outside the critical band of the expected frequency. "A signal that differed spectrally from the expected sound was not detected even though it had the same low pitch, based on a common fundamental frequency" (p. 215). The authors propose that prior knowledge of a signal may aid detection of that signal by actively fine-tuning the cochlea to certain frequencies and thus improving the signal-to-noise ratio for that particular signal.

Description of the Set of Auditory Alarms Developed by Patterson, Edworthy, Shailer, Lower, and Wheeler (1986) for Medical Equipment in Intensive Care Areas and Operating Theatres

The alarms developed by Patterson et. al. for use on medical equipment incorporate the design recommendations for auditory warning signals made by Patterson in his 1982 paper for the Civil Aviation Authority that were introduced earlier. The set of alarms under discussion are composed of 2 levels of 7 categories of alarms plus a short 'information available' acoustic signal. The 7 categories of warnings signals are: general, oxygenation, ventilation, cardiovascular, artificial perfusion, drug administration, and temperature. For each category there is an emergency warning and a cautionary warning signal.

All the alarm signals are comprised of a set of sound pulses referred to as a warning burst (of sounds). For Patterson et al.'s signals, the cautionary signals are all 200 msec in length and the emergency signals are 150 msec in length. Some of the emergency signals have delayed harmonics or more harmonics than the cautionary signals in an effort to increase their perceived urgency. The warning categories are differentiated by the number of sound pulses that occur in a 2 second interval, as well as by their pitch and the length of

the interpulse interval. The cautionary form of the warning has a slower temporal pattern (i.e. longer interpulse intervals) but the time ratios between pulses are the same.

Patterson and his colleagues have attempted to relate the number of bursts in a category to the number of syllables in that category as a mnemonic aid to remembering the meaning of the signal. For instance, the 'car-di-o-vas-cu-lar' category is composed of 6 sound pulses. However, this mapping of number of pulses to number of syllables in the category name is not consistent. For instance, the 'drug ad-min-is-tra-tion' category signal is composed of 8 sound pulses.

Aside from the mnemonic aid which might be applied to the temporal code of the auditory warning signal, temporal and pitch contour coding increase the distinctiveness of each warning signal so that even if the meaning associated with a particular acoustic signal is not remembered, the sound itself will at least not be confused with other warning signals.

Temporal Coding of Auditory Warning Signals

Existing hospital warning signals are either continuous signals (i.e. have no temporal pattern) or are composed of repeating patterns of on/off. Therefore, it is the pitch of the alarms that most often differ but it is usually a steady pitch, and quite often even the pitch is the same for different pieces of equipment. Temporal coding is more important than pitch coding for auditory warning signals since the temporal characteristics of sound are more easily remembered than the pitch. Patterson and Milroy (1980) and Roberts and Angiolillo-Bent (1988) found that subjects were able to remember sounds lasting 2 seconds or less better by their temporal characteristics than by their pitch.

Warren (1974) distinguishes between what he calls 'Type I auditory temporal discrimination' and 'Type II auditory temporal discrimination'. "Type I involves the attaching of distinguishing verbal labels to successive items" (p. 254). He states that previous reports from his laboratory "have shown that untrained listeners cannot name the

order of sounds in extended sequences of unrelated items such as hisses, tones, and buzzes at item durations of 200 msec, even though identification of order for the sounds of speech and music is accomplished readily at much shorter item durations". By 'extended sequences', he means sequences of four sounds (Warren, 1969, 1974) and he refers to the average speech sound as lasting 70 or 80 msec and the average length of a musical sound necessary to perceive the correct sequence of successive notes in music as 50 msec (Warren, 1969).

Warren's Type II auditory temporal discrimination "involves the global recognition of acoustically complex patterns consisting of successive sounds . . . Naming the order of phonemes is an example of Type II processing in speech perception, and requires prior recognition of syllabic temporal compounds" (p. 255). Based on this research, the attempt by Patterson and his colleagues to map syllables corresponding to each alarm pulse in order that personnel can more easily remember the meaning of the alarm is a good one.

The implications of Warren's research as it applies to the design of auditory alarms is that the pulses of sound that compose the alarms should be greater than 200 msec long if the temporal sequence of the patterns is going to be remembered by untrained listeners; they would thus be utilizing Warren's Type I strategy for remembering temporal sequences. However, attaching a speech mnemonic to the temporal code such as has been done by Patterson increases the chances that people will remember the temporal pattern of the alarms for signal pulses that are less than 200 msec long.

Using Sounds of Differing Pitch Contours

"Human beings, when faced with the task of learning and remembering a melodic line or a rhythmic pattern, generally encode how tones or temporal units are related to one another, not their absolute properties. We remember ups and downs -- the contour -- of a melody in its tonal context, for example, not the absolute frequencies of the sounds involved." (Hulse, 1987, p. 202-203). In a series of experiments described in this paper,

Hulse and his colleagues were able to show that songbirds appear to process complex temporal patterns in much the same way that humans do but found that songbirds are more biased toward absolute pitch in making their discriminations of complex sounds while humans are biased toward relative pitch discriminations.

Description of the Set of Auditory Alarms Developed by Stanford, McIntyre, and Hogan (1985) for Anaesthesia Monitoring Equipment

The set of 8 auditory alarms developed by Stanford et al. were designed to be less annoying than existing alarms on anaesthesia equipment and to be less susceptible to masking by operating room noises such as those emitted from the suction device, the skull drill, the grinder-rearmer, and the plaster saw. The components of each of the auditory signals are analogous to the vowel components low /i/, high /i/, low /a/, high /a/, low /u/, and high /u/. The length of these components (referred to by Patterson et al. as pulses) are either 50, 100, or 150 msec in length. A signal is composed of either 6 or 7 of these components and each signal is 500 msec in length. The 8 signals are differentiated by the length and order of components in each signal. Stanford et al. found that the signals were detected with at least 93% accuracy at a - 24 dB signal-to-noise ratio, the noise being the operating room equipment noise listed above.

In a second experiment, Stanford, McIntyre, Nelson, and Hogan (1988) measured subjects' affective responses to 7 commercially available auditory alarms on existing medical equipment and to their 8 auditory alarm signals. Eighteen of the 68 affective responses to the experimental set of signals were negative and 50 of them were positive. Eighty-nine of the 125 affective responses to the commercially-available signals were negative and 36 of them were positive.

General Overview and Rationale for Choosing the Parameters Incorporated into the Warning Signals to be Tested

In order to develop a set of warning signals that have been designed in a systematic way based on empirical evidence, it is necessary to establish the effects of varying acoustic parameters of sound on the perceived urgency of those sounds comprising the warning signal. In order to do this effectively, it is necessary to have a rationale for choosing some boundaries for these parameters; these constraints on design are related to the ergonomic recommendations previously presented. For instance, at least four harmonics should be incorporated into an auditory signal in order to protect that signal from being masked by background noise. For psychoacoustic reasons, sound pulses should be no less than 100 msec.. The reasoning associated with this design requirement and others is presented in the following few pages.

Length of Time Between Tone Bursts

In a series of four experiments, Hirst (1959) demonstrated that a separation time of between 15 and 20 msec is required for listeners to report correctly 75% of the time which of two sounds preceded the other. This time interval appeared to be independent of the types of sounds used: long or short, high or low frequency, narrow or wide bandwidth.

There will be a more adverse effect upon speech intelligibility as the intervals between tone bursts decrease since the ratio of the on time for the signal to its off time will be increasing. Patterson (1982) states that decreasing the interpulse interval will decrease the perceived urgency of a signal in which case we would have a situation where the more urgent signals would be more likely to have a deleterious effect upon speech intelligibility. This is necessarily an unfavourable condition since one would like the most urgent conditions to be tended to immediately. In the studies reported in the next section on intelligibility of speech in noise, the speech interruptions are unfortunately always studied

using equal ratios of speech segments to interruptions rather than incorporating unequal ratios, a desirable design feature in auditory warning signals.

Tone (Pulse) Duration

Patterson (1982) states that " the pulse should not be longer than necessary for three reasons: it increases the on-time of the warning; it reduces the intelligibility of the speech it interrupts; and it reduces the diversity of temporal patterns that can be used in the warning set" (p. 25). Patterson recommends pulse durations of 150 msec. However, with the use of pulse durations of this length, it is not possible to increase the distinctiveness of a signal using slow rates of amplitude modulation (am) or slow rates of frequency modulation (fm). Therefore, an argument will be presented for the use of pulses that range between 150 and 350 msec in duration.

Patterson's statement that longer pulses increase the on-time of the warning cannot be disputed, however, if speech is not unduly interrupted and the spectral properties of the alarm have been designed so as not to be annoying, this should not be a problem, and it will certainly be an improvement over the many continuous alarms now in existence. I would also argue that increasing the range in length of pulses that can be chosen would increase the diversity of temporal patterns that can be used in a warning set rather than decreasing it. That pulse lengths up to 350 msec are not likely to unduly degrade the intelligibility of speech is supported by the experiments that will be presented following a description of the work done by Miller and Licklider. Miller and Licklider's experiments do not support the use of pulses with lengths greater than 250 msec.

Miller and Licklider (1950) demonstrated the effects of gaps in speech upon intelligibility of that speech. The gaps they used were periods of silence and periods of noise with speech present in various signal-to-noise ratios (the signal in this instance being the speech, and the noise being white noise). The condition in which the gaps consisted of noise with speech present in signal-to-noise (S/N) ratios of -9 to -18 dB are most

representative of the conditions to be encountered in the clinical setting. The comparison here is confusing because the 'signal' being referred to in this context is not the auditory alarm but speech. The auditory alarms in this context is referred to as 'noise'. For the -9 S/N ratio condition, intelligibility dropped from 80% with 100 msec gaps to 75% with a 250 msec gaps and to 60% with 500 msec gaps. In the -18 S/N ratio condition, intelligibility dropped from 75% with 100 msec gaps to 65% with 250 msec gaps and to 45% with 500 msec gaps. Interpolating this data to reflect a -15 dB S/N ratio, the intelligibility is likely to be 77.5% with 100 msec gaps, 75% with 250 msec gaps, and 60% with 500 msec gaps. The flaw in using this experiment as an indication of the effects of noise gaps on the intelligibility of speech is that the authors used continuous speech composed of lists of monosyllabic words. Most speech encountered in everyday life is in context.

There is evidence that the gap length which is required before subjects perceive a gap is close to 300 - 350 msec when the speech is in context and the gap is filled with noise (Bashford, J. A., Jr., & Warren, R. M., 1987; Bashford, Meyers, Bradley, Brubaker, and Warren, 1988). When the gaps are a result of silences, however, the 'gap threshold' decreases to 50 to 100 msec.

Cherry and Wiley (1967) found that adding noise to gaps in degraded speech increased the intelligibility of that speech from 20% to 70%. Using sentences as the speech stimuli, Powers and Wilcox (1977) found intelligibility of speech interrupted by noise lengths of 340 msec to be 78%. As the S/N ratio became less favourable, intelligibility improved up to an S/N ratio of -24 dB and at S/N ratios worse than -24 dB intelligibility began to worsen again.

It is reasonable to assume that the speech that will be interrupted by the noise of the auditory signals will be in context and that the amplitude difference between the signal and speech will be at least 10 dB (i.e. the signal will be at least 10 dB above the speech level).

Another argument for using sound pulses greater than 200 msec in duration is that the threshold for sounds less than 200 msec results in an increased threshold for the sound (Plomp & Bouman, 1959; Scharf & Soren, 1986). Another way of saying this is that up to 200 msec, the longer a sound lasts, the louder it will sound with intensity held constant (Munson, 1947); at 200 msec an asymptote for this perceptual effect is reached. Beyond 200 msec, no additional loudness is gained for increased pulse duration.

It is believed that since the cochlea has no means of storing acoustic energy, temporal summation must take place in the auditory nervous system at some level beyond the cochlea (Zwislocki, 1960) and this requires a certain amount of time. Cowan (1987) proposes that the neural activity resulting from the sound outlasts the actual stimulus.

Advantage of Variable Dimension Coding

Variable dimension coding refers to the various ways that sounds can be manipulated over time in order to increase their uniqueness and in that way enable the people monitoring these sounds to more easily distinguish one alarm sound from another. The advantage of using temporal coding and pitch contour coding has been described previously. It is hoped that through the proposed research that the other acoustic parameters that contribute to the perceived urgency of sound can be distinguished in order that the sounds that are alarming a medically urgent condition will sound more alarming than a sound that is signalling a less medically urgent condition. Before describing the independent variables chosen for the current research, the variables investigated recently by J. Edworthy and her colleagues will be presented.

Acoustic Parameters Varied by J. Edworthy and her Colleagues and Their Effects on Perceived Urgency Ratings

In a series of 7 experiments, Edworthy, Loxley, Geelhoed, and Dennis (1989) investigated the effects of systematically varying the acoustic parameters of warning signals

in order to discover how subjects would rate the resulting sounds on urgency. The subjects first rank-ordered the stimuli that were not presented as paired comparisons but were presented as multiple paired comparisons, a technique developed by Gulliksen and Tucker (1961) in which 3 or more stimuli are actively compared with one another in each trial. The subjects were then asked to make magnitude estimations of the the stimuli. For the magnitude-estimation task, subjects were asked to imagine the most urgent sound possible and let this represent 100 on an urgency rating scale and to let 0 represent the most non-urgent sound they could imagine. They were then asked to assign a number between 0 and 100 to the sounds presented.

Experiment 1 tested the effect of 2 levels of fundamental frequency, 2 levels of harmonic regularity, and 3 levels of amplitude envelope shape. There were statistically significant main effects of fundamental frequency, of harmonic series, and of amplitude envelope. 530 Hz fundamental was judged to be more urgent-sounding than the 150 Hz fundamental, 10% irregular harmonics more urgent-sounding than the regular harmonics, and the regularly-shaped pulse amplitude and the slow onset amplitude were judged as being more urgent-sounding than the slow offset amplitude. There was also a fundamental frequency x envelope shape interaction. The authors' comment on this interaction is that "the Fundamental frequency x Envelope shape interaction is a topic of much speculation, and is possibly related to the increased salience of the harmonic series with both a lower fundamental and a slow onset envelope" (Edworthy et al., 1989, p. 13).

Experiment 2 included 2 levels of fundamental frequency , two levels of delayed harmonics, and three levels of harmonic regularity. Significant main effects were found for all of the parameters being investigated and there were no interaction effects. A 350 Hz fundamental frequency was judged as being more urgent-sounding than a 200 Hz one, random and 10% irregular harmonics were perceived as being more urgent than 50% irregular harmonics, and no delay in the harmonics was perceived as being more urgent than delayed harmonics.

Experiment 3 investigated two levels of rhythm and three levels of speed. There was a main effect for speed and a main effect for rhythm with no interaction. Fast burst presentation was judged as being more urgent than was a moderate one and a moderate presentation was judged as being more urgent than a slow presentation. A regular rhythm was judged as sounding more urgent than an irregular rhythm.

In Experiment 4, 2 levels of speed were combined with 3 levels of number of repeating units. There was a main effect for speed and a main effect for number of repeating units with no interaction. A fast speed was judged as being more urgent than a slow speed as in Experiment 3, and 4 units of sound were judged as being more urgent than 2 units and 2 units were judged as being more urgent than one unit.

Experiment 5 involved testing two levels of number of units and 3 levels of speed change. There was a main effect for both parameters being tested with no interaction. Two units of sound bursts was judged as being more urgent than one unit, and speeding from a regular rhythm and having a regular rhythm was judged as being more urgent than slowing from a regular rhythm.

Experiment 6 involved combining two levels of pitch contour with 3 levels of pitch range. There was a main effect for pitch contour as well as for pitch range with no interaction. A random contour was judged as being more urgent-sounding than a down-up one, and a large pitch range was judged as being more urgent than a moderate or small pitch range.

Experiment 7 combined 2 levels of pitch range with 3 levels of musical structure. There was only a main effect for musical structure and not for pitch range in this experiment with no interaction. An atonal structure was judged as being more urgent than an unresolved structure, and an unresolved structure was judged as being more urgent than a resolved structure.

The purpose of these kinds of experiments is discover the effect of various sound parameters on perceived urgency judgements. The results of the two experiments

conducted as part of this thesis research and the results of Edworthy et al.'s experiments show that this can be done. These experiments also demonstrate the necessity for empirical validation of intuitive predictions regarding the effects of various sound parameters on perceived urgency; some of the sound parameters investigated had an effect that was opposite to the effect predicted by Patterson (1982).

The need for empirical validation of the effects of various sound parameters on perceived urgency judgements does not mean that there are no difficulties involved in trying to obtain meaningful results - results that will aid designers of auditory alarms. One such difficulty is the nature of sound itself. All sounds are composed of a certain fundamental frequency, have a certain envelope shape, and have a power spectrum. Unless the sound is continuous, there is an interval of time between sound pulses. In order to determine the effect of a single sound parameter (for instance, fundamental frequency), all other parameters of the sound must be held constant, in which case a level at which to hold those parameters constant must be chosen. Another difficulty involves the limitation to the conclusions that can be drawn when a single parameter is varied. A single sound parameter may or may not have the same effect upon perceived urgency judgements when it is combined with different levels of other sound parameters - thus the necessity for testing for interaction effects.

Experiment 1

Introduction

The purpose of Experiment 1 was to determine which levels of a sound parameter will be judged as being more urgent than another using a paired comparison paradigm. The purpose of Experiment 2 was to take the most promising¹ parameters of Experiment 1 and

¹ 'Promising' in this context means parameters that were differentiated in terms of their urgency in one direction at least 75% of the time. An example of a promising parameter is one in which 75% of subject responses indicate that a shorter interpulse interval is more urgent-sounding than a longer one.

combine them in a factorial experiment. Some of the sound parameters chosen are of the same type as those used by Edworthy et al. (1989); this is pure coincidence. The parameters for Experiment 1 were chosen prior to receiving the copy of the report by Edworthy et al.. Some of the parameters were chosen for this experiment in order to empirically test the assumptions made about the parameters by others, and some of the parameters chosen were exploratory in nature. The parameters used in Experiment 1 were:

1. Pulse length and interpulse interval length
2. Amplitude modulation and pulse length
3. Number of harmonics
4. Spectral shape
5. Fundamental frequency
6. Frequency modulation and pulse length
7. Number and direction of frequency glides
8. Amplitude envelope shape
9. Number and direction of pitch steps

The Parameters Chosen by Edworthy et al. That Correspond to The Parameters Chosen for Experiment 1

The sound parameters used in this experiment that correspond to the ones used by Edworthy et al. include interpulse interval length (speed), fundamental frequency, and envelope shape. Edworthy et al. found that a stimulus with a higher fundamental frequency was judged as being more urgent than a stimulus with a lower fundamental frequency but they do not state how many harmonics are included in the stimuli used. They found that a regular or slow onset amplitude envelope was judged as being more urgent than a slow offset envelope. Their subjects judged a fast speed as being more urgent than a moderate speed and a moderate speed as being more urgent than a slow speed.

Rationale for Choosing Amplitude and Frequency Modulation as Acoustic Parameters to Vary

There is evidence that the human auditory pathway contains separate information-processing channels for coding frequency modulated (fm) signals and amplitude modulated (am) signals (Kay & Matthews, 1972; Regan & Tansley, 1979; Tansley & Suffield, 1983). Patterson (1982) recommends the use of pulses no longer than 100-150 ms for use in constructing warning signals in order to minimize disruption and masking. Since this restriction effectively eliminates using frequency modulation (fm) in order to make warning sounds more distinctive, he recommends incorporating a uni-directional frequency glide into a 100-ms pulse. However, arguments have been made under the section 'Tone (Pulse) Duration' for the use of tone pulses up to 350 msec in length. At such a length, slow am and fm are possible as is changing the number and direction of frequency glides incorporated into a sound burst.

Patterson does not make any statements concerning the perceived urgency of frequency modulated or amplitude modulated signals, but he does make a prediction concerning frequency glides:

A rapid sweep of the fundamental of a set of harmonics provides an effective means of drawing attention. It imparts a sense of urgency and so should be reserved for high-priority warning sounds. (Patterson, 1982, p. 40).

Choice of Amplitude and Frequency Modulation Rates

Zwicker (1952) reports maximum sensitivity of the ear at a variation rate of 4 Hz for both am and fm. Using a selective adaptation paradigm, Tansley and Suffield (1983) found the sensitivity for both am and fm to be greater at 4 Hz than at 8, 16, or 32 Hz. The following is a description given by Zwicker of the subjective effect of different am rates:

1 20 Hz audible variation of the loudness

20 100 Hz unevenness of the tone

> 100 Hz audibility of the side frequencies (p. AB 129)

These subjective effects are also experienced with fm, the only difference being that side frequencies become audible at 125 Hz rather than at 100 Hz. There are two reasons for choosing modulation rates below 20 to 30 Hertz. The first reason is that the unevenness of the tone that occurs between 20 and 100 Hertz is likely to be unpleasant (the musical equivalent to fm is vibrato which is usually regulated by singers and instrumentalists to a rate of 7 cycles per second; the musical equivalent of am is tremolo which is similarly held at 7 cycles per second (Truax, 1978)). The second reason involves the rate at which am and fm become indistinguishable. "Below a certain modulating frequency (the so-called phase-limited-frequency) the ear is able to distinguish between the two kinds of modulation and perceives the amplitude-modulation much better. Above this phase-limited-frequency there is no perceptible difference between frequency-modulation and amplitude-modulation. The phase-limit-frequency has a value of about 30 c/s [i.e. at 125 Hz] for low-frequency tones and rises to 1 kc/s for tones with a frequency of about 10 kc/s" (Zwicker, 1952, p.. AB125).

Rationale for Investigating Spectral Shape and Number of Harmonics

Spectral shape refers to the distribution of energy amongst the harmonic components used in a signal. Although Patterson (1982) does not specifically state that having more energy in the last five harmonics results in an increase in the perceived urgency of the warning sound, it is implied by the following statements:

If the first five harmonics have a significant proportion of the energy, the note will sound 'smooth', 'sonorous', and 'full'. As the energy shifts to higher harmonics the note sounds 'sharper' and it has more 'edge'. As a guideline, then, warning-sound quality and warning priority will be better matched if the low priority warnings, like attentions, have relatively more energy in the first five harmonics, and high-priority warnings, like immediate-action warnings, have relatively more energy in harmonics 6 - 10. (p. 37)

Patterson similarly states in this report that the greater the number of harmonics in a signal, the greater the perceived urgency. As far as can be determined, these assertions have not previously been tested empirically.

Method

Subjects Thirty-six subjects participated in Experiment 1. Half the subjects in each experiment were female and half were male. Subjects were between 18 and 40 years of age. They participated in the experiment as part of the course requirements for an introductory psychology course. Subjects were screened for normal hearing prior to participating in the experiment using a Bruel and Kjaer Audiometer Type 1800. Subjects were disqualified from participating in the experiment if they had more than a 15 dB loss of sensitivity at any frequency.

Apparatus The experiment was conducted in a sound attenuated booth. The sounds were generated by a general purpose computer-based system for the analysis and synthesis of sounds described in Appendix A. The sounds generated by the computer were sent to an EPI speaker Model 70C via a TTE model M7683 anti-aliasing filter attached to a Hewlett-Packard 350D Attenuator Set connected to a Boothroyd Stuart Meridien power amplifier. Subjects sat 1 meter from the speaker in the sound booth.

Stimuli The following is a description of the stimuli used in Experiment 1. Except for the stimuli in the eighth group of stimuli, the sound pulses had a 25 msec rise-time and an 25 msec decay. Stimuli were adjusted to be of equal loudness (79 dB(D) +/- 0.5 dB(D)) 1 meter from the speaker in the sound attenuated booth. As much as possible, any of the sound parameters that were not being tested in the paired comparisons, were held constant. Unless otherwise stated, the length of the sound pulses were 250 msec, the interpulse interval length was 250 msec, and the fundamental frequency was 350 Hz with 6 harmonics. The software programs written to generate the sounds and to run the experiment are presented in Appendix B.

Practice Trial: Melodic Contour

A 250 msec pulse length, 250 msec interpulse interval (IPI) and 6 harmonics were held constant for each triplet of pulses. In order to differentiate the melody, a 500 msec

silent interval was inserted between each pulse triplet. The varying pitch contours are as follows:

- (i) No variation. 375 Hz fundamental frequency.

— — — — — — — — —

- (ii) Rising-pitch contour.

400 Hz	400 Hz	400 Hz
375 Hz	375 Hz	375 Hz
350 Hz	350 Hz	350 Hz

- (iii) Falling-pitch contour.

400 Hz	400 Hz	400 Hz
375 Hz	375 Hz	375 Hz
350 Hz	350 Hz	350 Hz

1: Pulse Length and Interpulse Interval Length

Pulses were comprised of a 350 Hz fundamental frequency with 6 harmonics of equal amplitude. Pulse length and interpulse interval (IPI) length were varied. The levels included were:

- (i) 250 msec pulse length, 100 msec IPI
- (ii) 250 msec pulse length, 250 msec IPI
- (iii) 250 msec pulse length, 500 msec IPI
- (iv) 100 msec pulse length, 250 msec IPI
- (v) 500 msec pulse length, 250 msec IPI

2. Amplitude Modulation

The stimulus for this independent variable is set of pulses with a 350 Hz fundamental, 6 harmonics and a 250 msec interpulse interval (IPI). For the stimuli that were amplitude modulated, the depth of modulation was 100%. The levels of the independent variable are:

- (i) No am, 250 msec pulse.
- (ii) 4 Hz am, 250 msec pulse.
- (iii) 8 Hz am, 250 msec pulse.
- (iv) 16 Hz am, 250 msec pulse.
- (v) No am, 1 sec pulse.
- (vi) 4 Hz am, 1 sec pulse.

3. Number of Harmonics

Pulses for this set of paired comparisons were given a fundamental frequency of 350 Hz and a pulse length of 250 msec. Interpulse interval lengths were 250 msec. The number of harmonics (of equal amplitude) were varied. The number of harmonics at each level were:

- (i) The fundamental only.
- (ii) The fundamental plus the next 3 harmonics (4 harmonics in all).
- (iii) The fundamental plus the next 7 harmonics (8 harmonics in all).
- (iv) The fundamental plus the next 11 harmonics (12 harmonics in all).

4. Spectral Shape

Pulses had a 350 Hz fundamental frequency with 7 harmonics, a 250 msec pulse length, and a 250 msec interpulse interval. The shape of the spectrum in terms of the amplitude of the harmonics was varied.

The various spectral tilts tested are presented on the next three pages.

- (i) Equal energy in all the harmonics.

(ii) Stepwise spectrum with the majority of the energy in the middle harmonics.

(iii) Stepwise spectrum with the majority of the energy in the lower and higher harmonics.

(iv) More energy in the last 3 harmonics than in the first 3 harmonics.

(v) Square wave.

5: Fundamental frequency

Pulses were 250 msec in length. The IPI was 250 msec long, and there were 6 harmonics. The fundamental frequency (f_0) of the signals were varied. The fundamental frequencies tested were:

- (i) 143 Hz
- (ii) 330 Hz
- (iii) 500 Hz
- (iv) 660 Hz
- (v) 1000 Hz

According to the ergonomic recommendations presented above, 143 Hz corresponds to the lowest recommended pitch for warning signals and 1000 Hz represents the highest pitch recommended. 500 Hz was chosen as an intermediary pitch between these two extremes. The 500 Hz/1000 Hz paired comparison as well as the 330 Hz/660 Hz comparison were included in order to discover if pulses composed of fundamental frequencies one octave apart could be distinguished by subjects as reflected in their judgements.

6: Frequency Modulation

As with the amplitude modulated stimuli, a 350 Hz fundamental frequency pulse with 6 harmonics was used for all the levels of this independent variable and the degree of excursion was 10%. The levels are as follows:

- (i) No fm, 250 msec pulse.
- (ii) 4 Hz fm, 250 msec pulse.
- (iii) 8 Hz fm, 250 msec pulse.
- (iv) 16 Hz fm, 250 msec pulse.
- (v) No fm, 1 sec pulse.
- (vi) 4 Hz fm, 1 sec pulse.

7: Frequency Glides

The acoustic parameters chosen to vary for this independent variable were the number and direction of frequency glides in a sound pulse. A 350 msec pulse length, a 250 msec IPI and 6 harmonics were the parameters held constant. Each of the pulses had the usual 25 msec rise time before the glide began as well as the usual 25 msec decay. The levels of the independent variable are as follows. One straight line represents what will be referred to as a segment.

- (i) No glide. 300 msec segment.

- (ii) Upward glide. 300 msec segment.

- (iii) Downward glide. 300 msec segment.

- (iv) Up-down glide. 150 msec segments.

- (v) Down-up glide. 150 msec segments.

(vi) Up-down-up glide. 100 msec segments.

(vii) Down-up-down glide. 100 msec segments.

8: Amplitude Envelope

The pulses were composed of a 350 Hz fundamental frequency with 6 harmonics. The pulses were 325 msec in length and had an IPI of 250 msec.. The envelope shapes vary as follows.

(i) 25 msec rise-time, 275 msec full amplitude, 25 msec decay.

(ii) 100 msec rise time, 125 msec full amplitude, 100 msec decay.

- (iii) 25 msec rise-time, 200 msec full amplitude, 100 msec decay.

- (iv) 25 msec rise-time, 100 msec full amplitude, 200 msec decay.

- (v) 100 msec rise-time, 200 msec full amplitude, 25 msec decay.

- (vi) 200 msec rise-time, 100 msec full amplitude, 25 msec decay.

9: Pitch steps

The pulses for this independent variable are 350 msec in length, with a 250 msec IPI and 6 harmonics. The levels of the independent variable are as depicted here. At all levels, the rise-time was 25 msec, as was the decay-time.

- (i) 25 msec rise-time, 300 msec full amplitude at 375 Hz fundamental frequency, 25 msec decay.

- (ii) All lines represent 100 msec of sound. The fundamental frequencies progress from 350 Hz to 375 Hz and then back to 350 Hz.

- (iii) All lines represent 60 msec of sound. The fundamental frequencies progress from 350 Hz to 375 Hz to 400 Hz, back to 375 Hz and then back to 350 Hz.

- (iv) All lines represent 100 msec of sound. The fundamental frequencies progress from 375 Hz to 350 Hz and then back to 375 Hz.

- (v) All lines represent 60 msec of sound. The fundamental frequencies progress from 400 Hz to 375 Hz to 350 Hz, back to 375 Hz and then back to 400 Hz.

Procedure

Subjects sat 1 meter away from the speaker in the sound attenuation booth. Each subject was presented with all 9 groups of variables to make paired-comparison judgements. Order presentation of the independent variables was varied using a balanced Latin square design. Paired comparisons were made of all combinations and permutations of stimuli in random pairings within each group. For instance, for independent variable number 1, subjects received $2(N \times (N-1)/2) = 2(5 \times (5-1)/2) = 20$ stimulus pairs.

Subjects were presented with 3 seconds of the first level of the variable followed by a 2 second silence and then 3 seconds of the next level of the variable. Subjects were asked to make a judgement on which of the 3 seconds of sound sounded more urgent. Subjects were also allowed to judge the pairs of stimuli as being equally urgent-sounding. A practice trial was given to each subject. Subjects were allowed to take a break between groups of variables in order to prevent fatigue. The experiment took approximately 1 hr and 15 minutes.

Results

The results will be presented by variable group according to the percentage of subjects' responses in one direction. Only the variable levels for which > 50% of the responses were in one direction will be listed. Where there was no consistent trend (i.e. 50% of the responses were for the opposite direction and/or were no difference judgements) will not be listed. There will be a short summary of the meaning of the results following the result presentations. The greater than sign (>) represents the phrase "was judged as more urgent than".

1. Interpulse interval length and pulse length

IPI

100 ms > 250 ms (76.4%).
 250 ms > 500 ms (88.9%).
 100 ms > 500 ms (95.8%)

Pulse length

100 ms > 500 ms (63.9%)
 250 ms > 500 ms (51.4%)

IPI and Pulse length

500 ms pulse with 250 ms IPI > 250 ms pulse with 500 ms IPI (55.6%)

Conclusions: Shorter IPIs (a faster tempo) are judged as being more urgent than longer IPIs. The direction of the effect for pulse length (shorter pulse length more urgent-sounding) is moderate 1 but improves when there is a wider spread between the two levels of the parameter.

2. Amplitude Modulation

250 ms pulse length

No am > 4 Hz (65.3%)
 No am > 8 Hz (63.9%)
 No am > 16 Hz (65.3%)

1 second pulse length

No am > 4 Hz (59.7%)

Pulse length

250 ms no am > 1 sec no am (58.3%)
 250 ms 4 Hz am > 1 sec 4 Hz am (61.1%)

Conclusions: There is not much effect of amplitude modulation on perceived urgency except to decrease it somewhat. Pulse length does not have much of an effect on perceived urgency but the direction of the effect is consistent with the previous finding that a shorter pulse length tends to be judged as being more urgent.

3. Number of Harmonics

12	>	8	(76.4%)
8	>	4	(79.2%)
4	>	1	(80.5%)
12	>	4	(84.7%)
12	>	1	(87.5%)
8	>	1	(86.1%)

Conclusions: The greater the number of harmonics, the greater the perceived urgency.

4. Spectral Shape

The numbers here refer to different shapes of spectra tested and described earlier.

(i)	>	(ii)	(80.6%)
(i)	>	(iv)	(86.1%)
(i)	>	(v)	(69.4%)
(iii)	>	(ii)	(69.4%)
(iii)	>	(iv)	(86.1%)
(iii)	>	(v)	(75.0%)

Conclusions: A sound pulse that has a spectrum composed of harmonics of equal amplitude (i), one composed of harmonics with more energy in the the lower and higher harmonics than in the middle harmonics (iii), are judged as being more urgent-sounding than the other pulse spectrums tested.

5. Fundamental Frequency

330 Hz	>	143 Hz	(58.3%)
500 Hz	>	143 Hz	(61.1%)
660 Hz	>	143 Hz	(68.1%)
1 kHz	>	143 Hz	(76.4%)
500 Hz	>	330 Hz	(61.1%)
660 Hz	>	330 Hz	(73.6%)
1 kHz	>	330 Hz	(83.3%)
660 Hz	>	500 Hz	(69.4%)
1 kHz	>	500 Hz	(68.1%)
1 kHz	>	666 Hz	(72.2%)

Conclusions: The consistent but modest² finding of these paired-comparison results suggest that the higher the fundamental frequency, the greater the perceived urgency, especially when the difference in fundamental frequency is large as in the 143 Hz vs 1 kHz and 330 Hz vs 1 kHz cases. There is no indication that stimulus pairs are judged differently on perceived urgency when the stimuli in the pair are an octave apart versus when they are not.

6. Frequency Modulation

250 ms pulse length

No fm > 4 Hz (66.7%)
 No fm > 8 Hz (66.7%)
 No fm > 16 Hz (62.5%)

1 sec pulse length

No fm > 4 Hz (61.1%)

Pulse length

250 ms no fm > 1 sec no fm (52.8%)
 250 ms 4 Hz am > 1 sec 4 Hz am (51.4%)

Conclusions: There is not much effect of frequency modulation on perceived urgency except to decrease it somewhat. Pulse length does not have much of an effect on perceived urgency in these comparisons.

7. Frequency Glides

No glide > Down glide (84.7%)
 No glide > Up-down glide (84.7%)
 No glide > Down-up glide (69.4%)
 No glide > Up-down-up glide (72.2%)
 No glide > Down-up-down glide (73.6%)

Up glide > Down glide (86.1%)
 Up glide > Up-down glide (84.7%)
 Up glide > Down-up glide (72.2%)

² A modest effect is one where the direction of the effect is supported by greater than 50% of the judgements but by less than 75% of the judgements.

Up glide > Up-down-up glide (70.8%)
 Up glide > Down-up-down glide (84.7%)

Down-up glide > Up-down glide (61.1%)
 Down-up glide > Down-up-down (63.9%)

Up-down-up glide > Down glide (61.1%)
 Up-down-up glide > Up-down glide (61.1%)
 Up-down-up glide > Down-up-down glide (56.9%)

Down-up-down > Up-down (51.4%)

Conclusions: Except for the No glide vs Up glide comparison, No glide is judged as being more urgent than a glide; in the case of the No glide vs Up glide comparison, 43.1% of the responses claimed No glide is more urgent, 48.6% of responses were for the Up-glide, and the rest of the responses claimed they were equally urgent. A single Up glide is judged as being more urgent-sounding than any of the other glides. In general, a sound pulse that terminates in an up-glide will be judged as being more urgent-sounding than ones that terminate with a down-glide.

8. Envelope Shape

Rise

25 msec > 100 msec (61.1%)
 25 msec > 200 msec (69.4%)

Decay

25 msec > 100 msec (65.3%)
 25 msec > 200 msec (52.8%)

Rise and Decay

25 msec > 100 msec (75.0%)

Conclusions: Although the effect is modest, indications are that a shorter rise- and decay-time will be judged as being more urgent than a longer rise and/or decay when the pulses are of equal length.

2. Pitch Steps

Steady tone > Up-down pitch steps (87.5%)
 Steady tone > Up-up-down-down pitch steps (75.0%)
 Steady tone > Down-up pitch steps (76.4%)
 Steady tone > Down-down-up-up pitch steps (62.2%)

Up-up-down-down pitch steps > Up-down pitch steps (56.9%)

Down-up pitch steps > Up-down pitch steps (68.1%)

Down-down-up-up pitch steps > Up-down pitch steps (59.7%)
 Down-down-up-up pitch steps > Up-up-down-down pitch steps (65.3%)
 Down-down-up-up pitch steps > Down-up pitch steps (63.9%)

Conclusion: A steady tone is judged as being more urgent-sounding than any of the pulses containing pitch steps. Consistent with the results of the frequency glide comparisons, a sound pulse that terminates with pitch steps that are getting higher in pitch are more urgent-sounding to subjects.

Discussion

The results of Experiment 1 have served to indicate what level of a sound parameter will increase or decrease the perceived urgency of a set of sound pulses. Some of the results were expected but some of the results are seemingly counterintuitive, an argument for empirically investigating the effect of various sound parameters on perceived urgency.

The finding that the shorter the IPI (or the faster the tempo), the greater the perceived urgency is consistent with the findings of Edworthy, Loxley, Geelhoed, and Dennis (1989) and Hellier and Edworthy (1989). Also consistent with Edworthy et al.'s findings was the finding that the greater the fundamental frequency, the greater the perceived urgency. The finding that the greater the number of harmonics composing a sound pulse, the greater the perceived urgency of the pulse is consistent with Patterson's statement regarding the number of harmonics in a sound signal (Patterson, 1982). Similarly, the finding that a sound envelope with a shorter rise-time and a shorter decay-time will be perceived as being more urgent than a sound pulse with a longer rise and decay

is consistent with assertions made by Patterson's in his 1982 document for the British Civil Aviation Authority.

Some of the results of this experiment and one of the results of Edworthy et al.'s experiments (Edworthy et al., 1989) refute some of the claims previously made by Patterson (1982) concerning the direction of the effect of various sound parameters of judgements of perceived urgency. For instance, Edworthy et al. found that a regular rhythm was judged as being more urgent-sounding than an irregular one. Experiment 1 of this thesis produced results that suggest that a steady pulse is as urgent-sounding as an upward frequency glide but that a steady pulse is more urgent-sounding than any of the other frequency glides tested. This is not the effect predicted by Patterson:

A rapid sweep of the fundamental of a set of harmonics provides an effective means of drawing attention. It imparts a sense of urgency and so should be reserved for high-priority warning sounds (Patterson, 1982, p. 40).

This results of this experiment indicate that a distinction needs to be made between perceived urgency of an auditory signal and distinctiveness of an auditory signal. Although the two perceptions are not mutually exclusive, neither should they automatically be assumed to be the same. Frequency glides, frequency modulation, and amplitude modulation are likely to increase the distinctiveness of a signal, but the results of this experiment indicate that they will not necessarily increase the perceived urgency of the signal.

Another general finding of this experiment is that the number of judgements indicating the effect of varying a sound parameter to increase the perceived urgency of a signal will increase as the difference between the levels of the parameter is increased. For instance, the greater the difference in fundamental frequency between two signals, or the greater the difference in tempo, the more consistent the results.

Experiment 2

Introduction

The purpose of Experiment 2 was to discover the effect of combining various sound parameters on judgements of perceived urgency, and in order to discover the amount of variance in the dependent variable accounted for by each of the independent variables (the sound parameters). The term 'independent variable' is used to describe a sound parameter in order to clarify the design of the experiment, but it should be kept in mind that many sound parameters are not strictly independent due to the nature of sound.

Five of the nine sound parameters from Experiment 1 were chosen to be included in Experiment 2. Two criteria were used to decide which sound parameters and what levels of these parameters would be included in the second experiment: 1) consistency in the direction of the effect and 2) the total number of responses indicating that one level was more urgent than another level of the parameter. The five sound parameters chosen from Experiment 1 were:

1. Interpulse interval.
2. Number of harmonics.
3. Spectral shape.
4. Fundamental frequency.
5. Frequency glide.

A sixth sound parameter (loudness) was included in the experiment in order to determine its effect upon ratings of perceived urgency. It was expected that louder sounds would be judged as being more urgent than softer ones. Sound envelope and pulse length were held constant, the sound envelope being composed of a 25 msec rise and a 25 msec decay. All pulses were 250 msec long.

Method

Subjects. Forty subjects participated in Experiment 2. Half the subjects were female and half were male. Subjects were between 18 and 40 years of age. They participated in the experiment as part of the course requirements for an introductory psychology course. As in Experiment 1, subjects were tested for normal hearing prior to participating in the experiment and were disqualified from participating in the experiment if they had more than a 15 dB hearing loss at any frequency.

Apparatus: The apparatus used in this experiment were the same as that used in Experiment 1. As in Experiment 1, subjects were placed in the sound attenuation booth 1 meter from the speaker.

Stimuli. Two levels (one urgent level, and one non-urgent level) of 6 sound parameters were chosen to be included in the experiment. Five of the 6 sound parameters were chosen because they exhibited the most consistent results in terms of perceived-urgency judgements in Experiment 1. Loudness was included as a sixth parameter in order to determine what effect having two different loudness levels would have on perceived urgency judgements. The expectation was that the louder stimuli would be judged as being more urgent-sounding. The following is a table of the stimuli. Each stimulus was presented as a 3-second window of sound as in Experiment 1. The software programs written to generate the sounds and to run the experiment are presented in Appendix C.

<u>Variable</u>	<u>Low Urgency</u>	<u>High Urgency</u>
1. Interpulse Interval	400 msec	100 msec
2. Number of harmonics	5	11
3. Spectral shape	Level (iv)	Level (iii)
4. Fundamental Frequency	175 Hz	450 Hz
5. Frequency Glide	Up-down	No glide
6. Loudness	75 dB	90 dB

Rise- and decay time was held constant at 25 msec and pulse length was held constant at 250 msec. Two levels of 6 variables resulted in 64 stimuli. The power spectrum was the same for both of the levels of spectral shape.

Procedure. All 40 subjects listened to all 64 stimuli 5 times. Subjects were required to take a 5 minute break between each set of stimuli, resulting in 4 breaks over the 1 hr period. Each time the 64 3-second stimuli were presented to the subject, they were presented in a different random order. After listening to a stimulus, subjects entered their responses into the computer using a 7-point rating scale. The rating scale on the screen and on the keyboard was presented as a continuum from 1 to 7, 1 being labelled 'Not Urgent' and 7 being labelled 'Very Urgent'.

Results

A 2x2x2x2x2x2 within-subjects (repeated measures) analysis of variance was performed on one dependent variable (perceived urgency). There was a 'low urgency' (Lu) and a 'high urgency' (Hu) or level of each of the independent variables as determined by the results of Experiment 1. An α level of .001 was chosen as the determinant of statistical significance because, on a 7-point rating scale, differences in means at an α level less conservative than .001 are too small to be practically useful. In fact, it could be argued that given the amount of power in this within subjects' design, an additional criterion. The data were screened for normality and homogeneity of variance. There were no missing cases as subjects were required to respond before the next stimulus was presented. A casewise plot of the standardized residuals identified 9 multivariate outliers but since all 9 were very close to being within 3 standard deviations of the mean, and since the Mahalanobis' distance was not statistically significant, these cases were not removed from the analysis.

Table 1 lists the significance of the main effects and the interaction effects. The main effect of fundamental frequency (Fo) was not significant ($p < .103$).

Table 1. Significant main effects and interaction effects of variables in Experiment 2

Independent Variables	F-ratio	df	p
<u>Main effects</u>			
Loudness	187.785	1, 39	<.0001
Interpulse interval (IPI)	109.293	1, 39	<.0001
Spectral shape (Tilt)	103.451	1, 39	<.0001
Frequency glide (Fglide)	45.496	1, 39	<.0001
Number of harmonics	17.403	1, 39	<.0001
<u>2-way Interactions</u>			
#harmonics x Fo	75.092	1, 39	<.0001
#harmonics x Fglide	57.723	1, 39	<.0001
Fglide x Loudness	39.037	1, 39	<.0001
#harmonics x Loudness	34.888	1, 39	<.0001
Tilt x Fglide	21.161	1, 39	<.0001
<u>3-way Interactions</u>			
#harmonics x Fo x Fglide	23.011	1, 39	<.0001
Tilt x Fo x Fglide	18.625	1, 39	<.0001
#harmonics x Fo x Loudness	14.905	1, 39	<.0001
#harmonics x Tilt x Fo	12.790	1, 39	<.001

Graphs of the interaction effects can be found in Appendix D. The standard deviation of the means of the 64 stimuli ranged from .954 to 1.584. A regression analysis performed on the data show that the main effects account for 57% of the variance in the dependent variables ($R^2 = .57137$, adjusted $R^2 = .57041$). The squared semi-partial correlations for the main effects are as follows: Loudness .365, IPI .126, Fglide .057, Tilt .019, #harmonics .002, Fo .001. A graph of the means of the main effects are presented in Figure 1. These same means are displayed in a different way in Figure 2. When subjects are forced into the regression equation first, the effect of subjects is not significant ($p < .462$). The dependent variable entered into the regression equation was the mean of the 5 trials for each subject for each stimulus.

Figure 1. Mean urgency ratings of the two levels of the six sound parameters with the two levels (low urgency and high urgency) on the abscissa

Figure 2. Mean urgency ratings of the two levels of the six sound parameters with the sound parameters on the abscissa

Due to the large number of data points in the experiment (40 subjects x 64 stimuli = 2560 data points), one might wish to choose an arbitrary measure of a meaningful difference rather than using statistical differences as the criterion. For instance, one might decide that a difference of .5 in the 7-point rating scale constitutes a meaningful difference. If that were so, then the differences between the low urgency and high urgency levels of loudness, interpulse interval length (IPI), and frequency glide (Fglide) would be the only 'significant differences' in the levels of the main effects. The differences in the means between the 'low urgency' (Lu) levels and the 'high urgency' (Hu) levels of the independent variables are listed in Table 2.

Table 2. Differences between the means of the main effects of Experiment 2

	<u>Loudness</u>	<u>IPI</u>	<u>Fglide</u>	<u>Spectral shape</u>	<u>#Harmonics</u>	<u>Fo</u>
Hu	4.850	4.456	4.269	4.112	3.966	3.840
Lu	2.933	3.327	3.514	3.672	3.817	3.943
Difference	1.917	1.129	0.755	0.440	0.149	0.103

Discussion

The direction of the main effects is what was expected based on the results of Experiment 1 except for the effect of fundamental frequency (Fo). The results of Experiment 1 demonstrated a consistent albeit modest effect of Fo on perceived urgency: higher fundamentals were judged as being more urgent than lower ones. The number of judgements for the effect of Fo were less than those for the other parameters chosen to be included in Experiment 2; however, having alarms of varying fundamental frequencies is an important aspect of the design of auditory alarms, not only in order to have alarms in a set that are distinct from one another, but also in order to prevent masking. If it turns out

that F_0 has no demonstrable effect on perceived urgency judgements one way or another, then it would be possible to choose any fundamental that one wishes for any alarm. However, the results of Experiment 2, as well as one of the results of Edworthy et al. (1989) suggest that the effect of fundamental on perceived urgency ratings is not a simple formula when combined with other acoustic parameters. For instance, Edworthy et al. found an interaction between envelope shape and fundamental frequency.

Most of the interaction effects presented in Table 1 and graphed in Appendix D can be explained by the fact that there is no main effect of fundamental frequency and/or that the direction of the effect of the sound parameters in the interactions are the same as they are for the main effects but that the degree of effect differs resulting in slopes of differing angles. The downward slope in the 'low-urgency' fundamental ($L_u F_0$) line of the $F_0 \times \#$ harmonics interaction is a difference between a mean rating of 4.00 and 3.88, a statistically significant interaction, but not one that demonstrates a practically significant trend. The most interesting and unexpected interactions involve the interactions between the number of harmonics and frequency glide. It appears as if an Up-down frequency glide is more urgent-sounding when combined with fewer harmonics, especially when combined with a lower fundamental frequency.

General Discussion

Auditory alarms that sound as urgent (or non-urgent) as the condition they are alarming is a design feature that has, for the most part, been neglected by designers. An equally, or perhaps even more desirable feature of such alarms, is that they be distinctive so that personnel monitoring the alarms can ascribe a meaning to the alarm when they hear it. In order to make alarms distinctive, they have to be comprised of different sound parameters. Identifying which sound parameters will increase and which ones will decrease subjects' ratings of perceived urgency has been the focus of this thesis. In Experiment 1, subjects' rated the perceived urgency of a variety of sound parameters using

a paired-comparison paradigm. Several of these parameters were combined in a 6-way analysis-of-variance experiment (Experiment 2) in order to discover the combined effect on ratings of perceived urgency using a 7-point rating scale. Except for pulse lengths, design recommendations for auditory warning signals made by previous ergonomists, were adhered to in the construction of the stimuli for the two experiments. An extensive argument was presented in the introduction for the use of longer sound pulses than recommended by Patterson (1982). A paired-comparison paradigm was used in Experiment 1 in order to obtain subjects' judgements regarding the effect of various sound parameters on perceived urgency. The results demonstrated that:

1. Shorter interpulse interval lengths are more urgent than longer ones and that pulse length makes little difference, although shorter pulse lengths are judged as being more urgent-sounding more often than at chance level.
2. A signal with no amplitude modulation (am) is judged as being more urgent-sounding than a signal that has am when the depth is 100% (although the judgments for this effect only comprise about 60% of the judgements). Whether a signal has 4 Hz, 8 Hz, or 16 Hz am makes no difference to judgements of perceived urgency.
3. The more harmonics comprising a signal, the greater the perceived urgency of the signal.
4. Spectral shape can have a consistent and strong effect upon judgements of perceived urgency.
5. The higher the fundamental frequency, the greater the perceived urgency.
6. Signals with no frequency modulation (fm) are perceived as being more urgent-sounding than signals with frequency modulation. As with am, there is only a moderate effect in this direction. There is no difference between the perceived urgency of signals with 4 Hz, 8 Hz, or 16 Hz fm when the excursion is 10%.
7. A signal with no frequency glide or with a single frequency glide in an upward direction is judged as being more urgent-sounding than signals with any other kind of

frequency glide and in general, a sound pulse that terminates in an up-glide will be judged as being more urgent-sounding than ones that terminate with a down-glide.

8. Although the effect is modest, indications are that a shorter rise- and decay-time will be judged as being more urgent than a longer rise and/or decay when the pulses are of equal length.
9. A steady tone is judged as being more urgent than a sound that incorporates various pitch steps into the signal. In general, a signal that terminates in a rising pitch sequence will be judged as being more urgent than signals with a downward pitch sequence, although the effect is modest.

One of the more surprising results of Experiment 1 was that steady tones were judged as being more urgent-sounding than tones with amplitude modulation, frequency modulation, or frequency glides (except for a single upward frequency glide). The subjects themselves offered an explanation for this effect: following their participation in the experiment, many of the subjects volunteered the information that the signals that incorporated am, fm, or glides, sounded like the kinds of sounds they often heard when playing video-games. This explanation illustrates the belief that ratings of perceived urgency are largely governed by cultural factors, and are therefore subject to change over time as well as location. If this is the case, it brings into question the use of magnitude estimation procedures and the application of Steven's Power Law (see Stevens, 1975) to the relationship of sound parameters and judgements of perceived urgency, procedures used by Hellier and Edworthy (1989).

Stevens' Power Law ($j = kf^b$) describes the growth of sensation magnitude (j) as a power function of the stimulus magnitude (f). The constant (k) depends on the unit of measurement but the exponent (b) will differ depending on the modality of sensation. This power function is usually applied to sensations that will not likely to change over time and that are culturally independent, such as loudness. However, it can perhaps be argued that there are certain sound parameters such as loudness and tempo that are resistant to cultural

factors and that it is therefore appropriate to relate them to perceived urgency judgments using Steven's power function.

The results of Experiment 1 and the results of experiments performed by Edworthy et. al. (1989) demonstrate the need for empirical evidence for the effect of varying sound parameters on ratings of perceived urgency since some of the results contradict predictions made by Patterson (1982).

The results of Experiment 1 and Experiment 2 are reasonably consistent:

Louder signals are judged as being more urgent-sounding than softer ones.

Signals with shorter interpulse intervals (faster tempos) are judged as being more urgent-sounding than longer interpulse intervals (slower tempos).

A signal composed of a steady pulse results in judgements of greater perceived urgency than signals that incorporate frequency glides.

Spectral shape can be manipulated to increase or decrease ratings of perceived urgency.

It is yet to be determined whether the direction of the effect of the number of harmonics and of the fundamental frequency shown in Experiment 1 holds up when these two parameters are combined with other sound parameters. The interaction between the number of harmonics, the fundamental frequency, and frequency glide is one that requires more research in order to fully explain this interaction effect.

It is discouraging but useful to know that loudness accounts for so much of the variance in perceived urgency ratings of auditory signals when five other parameters are included in the stimuli. It is discouraging because working with a large number of loud hospital alarms would likely irritate staff responsible for monitoring those alarms over a number of hours, and because loud alarms are also likely to startle and disturb patients. However, a compromise might be to make critical alarms louder if they are not attended to within a reasonable length of time. Except for loudness, the other parameters in both Experiment 1 and in Experiment 2 were chosen so as not to be irritating. Most irritating sounds will likely sound urgent to some extent. However, hospitals and other places

where warning signals are necessary are already inundated with the sound of irritating alarms.

The information obtained from Experiments 1 and 2 will be of limited use to designers of auditory alarms until the interaction effects involving fundamental frequency are explored further. Given the need for a set of auditory alarms in a setting, it is imperative that the alarms have different pitches so as not to be confused with one another and so that they will not mask each other. This thesis research has, however, provided *some* useful information for designers. Four of the five sound parameters tested in Experiment 1 demonstrated the same direction of effect on perceived urgency judgements when they were combined in a factorial experiment. Knowing how much variance in these judgements can be accounted for by loudness is useful. Even though the effect of fundamental frequency was unpredictable in Experiment 2, much of the variance (57%) in the dependent measure (ratings of perceived urgency) was accounted for by the other independent variables in the experiment. If the stimuli are segregated so that there is no difference in loudness levels, Experiment 2 provides designers with 32 stimuli that can be used for auditory warning signals and these 32 stimuli can be rank-ordered according to their perceived urgency.

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Appendix A

McGill Speech and Hearing Laboratory description of the auditory research system used for Experiments 1 and 2.

More information regarding the system can be obtained by contacting

**Dr. Albert S. Bregman
McGill University
Department of Psychology
Stewart Biological Sciences Bldg.
1205 Dr. Penfield Avenue
Montreal, Quebec H3A 1B1**

**Email address: in09@mcgillb.bitnet
 or: in09@musicb.mcgill.ca
Telephone: (514) 398-6103
Fax number: (514) 398-4896**

MCGILL SPEECH AND HEARING LABORATORY
DESCRIPTION OF THE AUDITORY RESEARCH SYSTEM
REVISED JUNE 20, 1990

HARDWARE

The system runs on any IBM-AT bus-compatible computer with a math coprocessor. We originally used COMPAQ 386/20's but have converted to cheaper, faster, and more reliable clones. The computer may either use a monochrome analog VGA screen or a colour VGA screen (we currently are using a Seiko). These are needed for high-resolution spectrograms. A mouse is used as a pointing device. The system sits on a desk-top. It consists of the computer, two miniature speakers, and two boxes the size of college dictionaries (one containing anti-aliasing filters and the second a 6-channel mixer). A two-channel audio conversion system is hidden inside the computer chassis. The analog conversion has 16 bit resolution and we achieve, in output from hard disk, stereo sampling rates of at least 44k samples per channel per second (simple playback without monitoring the subject's reaction time). System noise is inaudible.

SOFTWARE

The software consists of a number of compatible modules running under DOS. These include two interconnected languages written by William Henke that, together with utility programs, make up the MITSYN system for signal analysis and synthesis. There is also the MAPLE language, written by André Achim, which controls audio-based laboratory experiments, and a High Quality Spectrogram program.

MITSYN

[copyright William L. Henke]

All the MITSYN modules are selected from a common menu. The first MITSYN language, called MCL, defines computations by sequences of commands. The second specifies them by means of a block diagram designed on the screen by the user.

MITSYN COMMAND LANGUAGE (MCL)

This is a general purpose language with all the usual arithmetical, logical, program-structuring and sequence-control statements. In addition, however, it has special computational concepts and data types that facilitate signal processing, graphics, and mouse-based interaction. It can also spawn external programs. MCL is interpreted rather than compiled. This allows debugging facilities (such as syntax error-checking and reporting, pause points, single-step operation, access to the table of currently defined symbols, current memory-usage statistics, etc.) to be built into it. However, it is quite fast, because the interpreted operations are usually very high-level concepts that activate lengthy machine language programs.

SUPPLIED MCL UTILITY PROGRAMS. The MCL language has been used to write interactive utilities that are supplied as canned programs with the system. They include the following menu-based graphic editors for waveforms, vectors, and scores, as well as programs for signal processing. Many of the editors, as well as supplying the functions offered in their menus, also allow the user to access the full power of MCL from within the editor. This is useful because the objects shown on the screen can be accessed by MCL commands.

SCANLAB - This utility allows the user to record and play audio signals and to analyze either recorded or synthesized signals. The signal can be examined at different levels of detail, measured, edited, and segments extracted for splicing. All or part of it can be played back. Events in the signal can be detected visually and labels can be manually written into an associated time-marked file. This file can control later automatic analyses or syntheses. Spectra, either single, or in the form of waterfall displays or grey-level spectrograms, can be viewed. This program is written in MCL code that can easily be enhanced by the user (e.g., adding new menu items and functions).

EDIT HARMONIC VECTOR - This graphic editor allows a waveform to be specified from a graph of its spectrum. The latter can be created by using the mouse or by formulas (or both). The resulting waveform can be viewed or played as audio. It is often passed to the block-diagram language to serve as the waveform for an oscillator.

EDIT VECTOR - This graphic editor allows a function (vector) to be edited by applying mathematical computations or by drawing it with a mouse (or both). The resulting vector can be passed to the block diagram language to serve, for example, as the amplitude envelope of a tone, or the shape of an arbitrary transfer function. Vectors can also (optionally) be stored as text files using MCL commands.

EDIT SCORE - This graphic editor allows a "score" (a picture with time as the x-axis) to be created on the screen either by use of the mouse or by keyboard commands. Line segments and other notations written on this score are used to specify values that change over time, much as the notes on a musical score do. The score is fed later into a block-diagram "configuration" that carries out analysis or synthesis, where it exerts a temporal control over the processing. The score might, for example, specify formant tracks for a voice synthesis. The editor has various windowing, scaling and part-viewing capabilities. Since the pictorially displayed scores are always converted to text files when they are stored on disk, and converted to pictures when read from disk, scores can easily be created by external programs or created and spliced using a text editor.

OTHER "CANNED" MCL MODULES - There are over 50 of these. They perform miscellaneous signal-processing functions. Examples are "log magnitude spectrum with cepstral smoothing", "nth order LPC spectrum", "autocorrelation function", "plot the response of an FIR filter", "plot an inter-event interval histogram", and so on. Since the MCL code is supplied, users can tailor the modules to their own needs or call them from within larger MCL programs. Other user-created modules can be added to this library (e.g., Brian Roberts has provided one that plots the neural "excitation function" of a signal).

MITSYN'S BLOCK-DIAGRAM (STREAM-PROCESSING) LANGUAGE

This language can do either analysis or synthesis. The user designs the computations by using a mouse to "wire up" a block diagram on the screen. Its elements are rectangular blocks connected by "wires". These blocks represent signal-processing "devices". The wires represent the flow of the signal from one device to another. Later, the program that interprets this picture causes the signal to be processed as it would have been if these devices had been real ones. Examples of blocks are oscillators, amplifiers (multipliers), readers of disk files that contain previously recorded or synthesized sounds, writers to disk files, envelope generators, filters, random number (noise) generators, mixers, integrators, delay buffers, arithmetic and logical operators, triggers, event histogram generators, and even a block that passes values out to the MCL language. Any kind of block can be used as many times as desired in any computation (until memory is exhausted). Results of previous runs can be fed into the current one; so the amount of complexity of computation is unlimited. Configurations of blocks can employ feedback loops. There are 101 types of primitive blocks in the language, and the user can extend this number by using the blocks that reach outside the block-diagram language to activate MCL programs, which could, in turn, spawn programs written in other languages.

Commonly used configurations of primitive blocks can be made into macro-blocks. These can then be used in larger configurations as "black boxes" whose inner structure is hidden from the user. Macro-blocks can contain other macro-blocks. This permits a sort of structured programming in which the efforts of one user can be made accessible to others in the form of a macro-block library. There are 39 system-supplied macro-blocks including ones that concatenate segments from different signal files, act as FM oscillators, add reverberation to a signal, accept values from the computer console, and synthesize vowels.

An important block is the one that reads values from a score. It provides the link between scores and block-language configurations. Scores have been described earlier. They allow dynamically changing values to be fed into either a synthesis or an analysis. For example, a series of notations on a score could be used to tell the block diagram processor how to move the centre frequency of a "zero" filter over time, scooping out a moving formant from a recorded natural voice, and how to control an oscillator that replaced the missing sound with a tone gliding on the same frequency trajectory, presented in the contralateral ear. The trajectory would have come from a previous analysis of the signal using the High Quality Spectrogram program. The computations (e.g., the filter and oscillator of the above example) are defined in the block diagram language but the changes in their parameters over time are specified in the score.

Although our current hardware only allows recording and playback of two-channel signals, the number of channels in MITSYN's computations is not limited. As a synthesizer, the block-diagram language is very general. A few examples that show its power include: synthesizing simultaneous voices at different locations in space, speeding up a voice without changing its frequency, mixing recorded and synthesized musical instruments, and spectrally modifying real sounds. It also is used to carry out many forms of analysis (e.g., filtering a signal, or detecting classes of events in it).

MCL and the block diagram language cooperate in two ways: they both deal with the same data types, and they share the values of variables. For example MCL could write a score, then activate a block-diagram process and send the score name and other parameters to it. It could also set the values of variables or vectors to be used in the block processing. The block language could, in turn, send data to MCL. MCL can start a program in the block language or vice-versa. The difference is that the basic MCL processes (such as DFT) operate on finite vectors of data whereas the block-diagram process thinks in terms of sample-by-sample processing of signal streams of indefinite length with only a limited amount of memory for previous samples.

FILTER DESIGN. A program for designing a finite impulse response (FIR) filter is included in the system. This design can then be used by the Transversal Filter block in the block-diagram language.

EXPERIMENT-CONTROL LANGUAGE (MAPLE) [copyright André Achim]

A third language, MAPLE (Manager of Auditory Perception and Linguistic Experiments), runs outside the MITSYN system but uses signals that have been synthesized or recorded in MITSYN. Its job is to run experiments that use segments of sound that have to be concatenated into patterns, for example, cycles of sounds, in real time without glitches, while making decisions and collecting data.

MAPLE allows the user to conveniently define the abstract pattern of a trial (timing, repetitions, and so on) independently of the details of each trial. It then substitutes different values for each trial (signals to be used, the amplitude at which to play them, silence durations, etc.) into this pattern, over the course of the experiment. This can be done according to either a fixed predefined script, a request for randomization, or on-line decisions, such as replacement of trials having long reaction times or incorrect responses. The gathering of decision data and reaction times can be done concurrently with the presentation of an unbroken stream of sound presented at a high sampling rate. MAPLE is built on top of the commercially sold ASYST laboratory-control system. This strategy protects it from technological change because the ASYST company keeps providing drivers for new hardware. ASYST also offers many data-analysis and editing capabilities.

HIGH QUALITY SPECTROGRAM PROGRAM (HQS) [Copyright McGill Speech and Hearing Laboratory]

This program can be accessed from within MITSYN or directly from the DOS operating system. It is used from MITSYN by starting SCANLAB, the utility that examines, plays, measures, and edits signals. Within SCANLAB, the user can specify the portion of the signal to view and can set other display parameters. At this point, the user can spawn HQS which has its own menu of commands. HQS displays a smoothed grey-level spectrogram image and allows intensity scaling and the choice of DFT analysis window size and step size. It also produces high-resolution spectrograms on laser or other 300 dpi printers.

Appendix B

This appendix is composed of the software programs used to run Experiment 1.

Below are a list of the suffixes used indicating the type of program.

.mpl indicates a MAPLE program

MAPLE stands for Manager of Auditory Perception and Linguistics Experiments

.des indicates a design table

.mcl indicates a Mitsyn command language program

.mls indicates a Mitsyn low-level score program

.msc indicates a Mitsyn stream processor configuration

```
* exp1s36.mpl
* This is an example of the programs used to run
* Experiment 1 using a balanced Latin square design
* for determining the order presentation of the
* independent variables.
* Since there are 9 independent variables,
* 18 files were required.
* Subjects 1 and 19 received the same presentation order
* as did subjects 2 and 20 etcetera.
```

```
SCREEN.CLEAR
```

```
." Hit the <Enter> key when you are ready to start."
KEY DROP
```

```
load d:\kathy\nine\exp1test\exp1test.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\exp1test\exp1test.dat
```

```
SCREEN.CLEAR
```

```
." Hit the <Enter> key to continue."
KEY DROP
```

```
load d:\kathy\nine\ivp\ivp.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\ivp\ivp.dat
```

```
SCREEN.CLEAR
```

```
." Hit the <Enter> key to continue."
KEY DROP
```

```
load d:\kathy\nine\iv9\iv9.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv9\iv9.dat
```

```
SCREEN.CLEAR
```

```
." Hit the <Enter> key to continue."
KEY DROP
```

```
load d:\kathy\nine\iv1\iv1.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv1\iv1.dat
```

```
SCREEN.CLEAR
```

```
." Hit the <Enter> key to continue."
KEY DROP
```

```
load d:\kathy\nine\iv8\iv8.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv8\iv8.dat
```

```
SCREEN.CLEAR
```

```
." Hit the <Enter> key to continue."
KEY DROP
```

```
load d:\kathy\nine\iv2\iv2.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv2\iv2.dat
```

SCREEN.CLEAR
." Hit the <Enter> key to continue."
KEY DROP

load d:\kathy\nine\iv7\iv7.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv7\iv7.dat

SCREEN.CLEAR
." Hit the <Enter> key to continue."
KEY DROP

load d:\kathy\nine\iv3\iv3.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv3\iv3.dat

SCREEN.CLEAR
." Hit the <Enter> key to continue."
KEY DROP

load d:\kathy\nine\iv6\iv6.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv6\iv6.dat

SCREEN.CLEAR
." Hit the <Enter> key to continue."
KEY DROP

load d:\kathy\nine\iv4\iv4.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv4\iv4.dat

SCREEN.CLEAR
." Hit the <Enter> key to continue."
KEY DROP

load d:\kathy\nine\iv5\iv5.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\nine\iv5\iv5.dat

SCREEN.CLEAR
." That is the end of the experiment. Thank you for your participation
KEY DROP


```
\ practice.mpl
\ program to run the practice trial
\ independent variable (melody contour)
```

```
clean
maple.init
```

```
\ atom definition
```

```
11 -- d:\kathy\nine\ivp\350hz.ss
12 -- 375hz
13 -- 400hz
```

```
\ Define experimental sequences
```

```
1 sequence
  12 200 msec.silence
  12 200 msec.silence
  12 200 msec.silence
  12 200 msec.silence
  12 200 msec.silence
  12 200 msec.silence
end.sequence
```

```
2 sequence
  11 200 msec.silence
  12 200 msec.silence
  13 200 msec.silence
  11 200 msec.silence
  12 200 msec.silence
  13 200 msec.silence
end.sequence
```

```
3 sequence
  13 200 msec.silence
  12 200 msec.silence
  11 200 msec.silence
  13 200 msec.silence
  12 200 msec.silence
  11 200 msec.silence
end.sequence
```

\ Experimental pattern and screen display

```
pattern
  clear.display
    500 msec.silence
    from.column 1 #play
    2000 msec.silence
    from.column 2 #play

  after.sounds:
    " 1 -- first set sounded more urgent
    " display.text
    " 2 -- second set sounded more urgent
    " display.text
    " 0 -- both sounded equally urgent
    " display.text
    " 6 -- undecided
    " display.text
    response 1 2 6 0 end.response to.column 3
    from.column 3 6 =?
    if.true get.count 1 M+ set.count end.if

end.pattern

read.table ivp.des
1 set.design.table
```

```

\ ivp.des
\ This is the design table for
\ the practice trial of Experiment 1.
\ Design tables control the randomization
\ of sequences.
\ The first column indicates the first
\ sequence to be played, the second
\ column indicates the second sequence
\ to be played.

```

```

1 2
1 3
2 3
2 1
3 1
3 2

```

```

! practice.mcl
! creating a set of ss files to run the
.! practice trial (melodic contour)

```

```

create/ss 350hz.ss
run complex 350hz 350hz .5012

```

```

create/ss 375hz.ss
run complex 375hz 375hz .6310

```

```

create/ss 400hz.ss
run complex 400hz 400hz .6310

```

```

!350hz.MLS
w 0 0 0.31 1
N1 0.035 0.25
N2 0 0.025 1
W0.225
N2 1 0.025 0
W0.075
B99

```

```

!375hz.MLS
w 0 0 0.31 1
N1 0.0375 0.25
N2 0 0.025 1
W0.225
N2 1 0.025 0
W0.075
B99

```

```

!400hz.MLS
w 0 0 0.31 1
N1 0.04 0.25
N2 0 0.025 1
W0.225
N2 1 0.025 0
W0.075
B99

```

FILE: Open Save save-As eXit Quit Macroize

RUN

complex.MSC 28-Jul-1998 17:42:57 NITSYN Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

```
\ 1st independent variable (IPI length)
```

```
clean  
maple.init
```

```
\ atom definition
```

```
11 -- d:\kathy\nine\iv1\complex.ss  
12 -- pulse100  
13 -- pulse500
```

```
\ Define experimental sequences
```

```
1 SEQUENCE  
  11 50 msec.silence  
  end.sequence  
  
2 SEQUENCE  
  11 200 msec.silence  
  end.sequence  
  
3 SEQUENCE  
  11 450 msec.silence  
  end.sequence  
  
4 SEQUENCE  
  12 200 msec.silence  
  end.sequence  
  
5 SEQUENCE  
  13 200 msec.silence  
  end.sequence
```

```
\ experimental pattern and screen display
```

```
pattern  
  clear.display  
  500 msec.wait  
  from.column 1 cycles  
  from.column 2 #play  
  end.cycles  
  2000 msec.silence  
  from.column 3 cycles  
  from.column 4 #play  
  end.cycles
```

```
after.sounds:
```

```
" 1 -- first set sounded more urgent  
  " display.text  
" 2 -- second set sounded more urgent  
  " display.text  
" 0 -- both sounded equally urgent  
  " display.text  
" 6 -- undecided  
  " display.text  
response 1 2 6 0 end.response to.column 5  
from.column 5 6 =?  
if.true get.count 1 M+ set.count end.if
```

```
end.pattern
```

```
read.table iv1.des  
1 set.design.table
```

```

\ iv1.des
\ This is the design table for IV1.
\ This design table specifies the
\ number of cycles to be played (Columns 1 and 3)
\ and then the sequence number to be played (Columns 2 and 4).

```

```

8 1 6 2
8 1 4 3
8 1 8 4
8 1 4 5
6 2 4 3
6 2 8 4
6 2 4 5
4 3 8 4
4 3 4 5
8 4 4 5
6 2 8 1
4 3 8 1
8 4 8 1
4 5 8 1
4 3 6 2
8 4 6 2
4 5 6 2
8 4 4 3
4 5 4 3
4 5 8 4

```

```

! iv1.mcl
! creating a ss file for iv1

create/ss complex
run complex complex complex .5012

create/ss pulse100
run complex pulse100 pulse100 1

create/ss pulse500
run complex pulse500 pulse500 .4467

```

```
!complex.MLS
w 0 0 0.31 1
N1 0.035 0.25
N2 0 0.025 1
W0.225
N2 1 0.025 0
W0.075
B99
```

```
!pulse100.MLS
w 0 0 0.16 1
N1 0.035 0.1
N2 0 0.025 1
W0.075
N2 1 0.025 0
W0.075
B99
```

```
!pulse500.MLS
w 0 0 0.56 1
N1 0.035 0.5
N2 0 0.025 1
W0.475
N2 1 0.025 0
W0.075
B99
```

FILE: Open Save save-As eXit Quit Macroize

RUN

complex.MSC 28-Jul-1998 16:39:28 NITSYN Stream Processor Configuration

complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

```
\ iv2.mpl
\ this is a program to run the
\ 2nd independent variable (am)
```

```
clean
maple.init
```

```
\ atom definition
```

```
11 -- d:\kathy\nine\iv2\am1.ss
12 -- am2
13 -- am3
14 -- am4
15 -- am5
16 -- am6
```

```
\ Define experimental sequences
```

```
1 SEQUENCE
```

```
11 200 msec.silence
11 200 msec.silence
11 200 msec.silence
11 200 msec.silence
11 200 msec.silence
11 200 msec.silence
end.sequence
```

```
2 SEQUENCE
```

```
12 200 msec.silence
12 200 msec.silence
12 200 msec.silence
12 200 msec.silence
12 200 msec.silence
12 200 msec.silence
end.sequence
```

```
3 SEQUENCE
```

```
13 200 msec.silence
13 200 msec.silence
13 200 msec.silence
13 200 msec.silence
13 200 msec.silence
13 200 msec.silence
end.sequence
```

```
4 SEQUENCE
```

```
14 200 msec.silence
14 200 msec.silence
14 200 msec.silence
14 200 msec.silence
14 200 msec.silence
14 200 msec.silence
end.sequence
```

```
5 SEQUENCE
```

```
15 200 msec.silence
15 200 msec.silence
end.sequence
```

```
6 SEQUENCE
```

```
16 200 msec.silence
16 200 msec.silence
end.sequence
```

\ experimental pattern and screen display

pattern

clear.display

500 msec.wait
from.column 1 #play
2000 msec.silence
from.column 2 #play

after.sounds:

" 1 -- first set sounded more urgent
" display.text
" 2 -- second set sounded more urgent
" display.text
" 0 -- both sounded equally urgent
" display.text
" 6 -- undecided
" display.text
response 1 2 6 0 end.response to.column 3
from.column 3 6 =?
if.true get.count 1 M+ set.count end.if

end.pattern

read.table iv2.des
1 set.design.table

\ iv2.des

1	2	
1	3	
1	4	
1	5	! iv2.mcl
1	6	! creating a set of ss files to run
2	3	! the 2nd independent variable (am)
2	4	
2	5	create/ss am1.ss
2	6	run am 0 0 complex am1.ss .5012
3	4	
3	5	create/ss am2.ss
3	6	run am 4 1 1complex am2.ss .8913
4	5	
4	6	create/ss am3.ss
5	6	run am 8 1 1complex am3.ss .8913
2	1	
3	1	create/ss am4.ss
4	1	run am 16 1 1complex am4.ss .8913
5	1	
6	1	create/ss am5.ss
3	2	run am 0 0 longam am5.ss .4467
4	2	
5	2	create/ss am6.ss
6	2	run am 4 1 1longam am6.ss .7943
4	3	
5	3	
6	3	
5	4	
6	4	
6	5	

```
!complex.MLS
w 0 0 0.31 1
N1 0.035 0.25
N2 0 0.025 1
W0.225
N2 1 0.025 0
W0.075
B99
```

```
!1complex.MLS
w 0 0 0.31 1
N1 0.035 0.25
N2 0 0.025 1
W0.225
N2 1 0.025 0
W0.075
B99
```

```
!longam.MLS
w 0 0 1.061 1
N1 0.035 1
N2 0 0.025 1
W0.975
N2 1 0.025 0
W0.075
B99
```

```
!1longam.MLS
w 0 0 1.061 1
N1 0.035 1
N2 0 0.025 1
W0.975
N2 1 0.025 0
W0.075
B99
```

An circuit

P2. % depth (0 to 1)

P4. OutSS Name

P5. Attenuator

FILE: Open Save save-Hq eXit. Quit Macroize

RUN

complex.msc 28-Jul-1998 16:35:39 NITSYN Stream Processor Configuration

complex tone of varying freq, amp, and #of harmonics

P1. outss

P2. score

P3. Attenuator

```

\ iv3.mpl
\ program to run the 3rd
\ independent variable (# of harmonics)

clean
maple.init

\ atom definition

1 -- d:\kathy\nine\iv3\1harm.ss
2 -- 4harm
3 -- 8harm
4 -- 12harm

pattern
clear.display
  500 msec.wait
  6
  cycles
  from.column 1 #play
  200 msec.silence
  end.cycles
  2000 msec.silence
  clear.display
  6
  cycles
  from.column 2 #play
  200 msec.silence
  end.cycles
after.sounds:
  " 1 -- first set sounded more urgent
  " display.text
  " 2 -- second set sounded more urgent
  " display.text
  " 0 -- both sounded equally urgent
  " display.text
  " 6 -- undecided
  " display.text
response 1 2 6 0 end.response to.column 3
from.column 3 6 =?
if.true get.count 1 M+ set.count end.if

end.pattern

read.table iv3.des
1 set.design.table

```

\ iv3.des

1 2
1 3
1 4
2 3
2 4
3 4
2 1
3 1
4 1
3 2
4 2
4 3

```
! iv3.mcl
! creating a set of stimuli for
! the 3rd independent variable
! (350 Hz tone with 1, 4, 8, and
! 12 harmonics)

create/ss 1harm.ss
run 1harm complex1 1harm      1

create/ss 4harm.ss
run 4harm complex2 4harm      .5623

create/ss 8harm.ss
run 8harm complex3 8harm      .5012

create/ss 12harm.ss
run 12harm complex4 12harm    .4467
```

FILE: Open Save save-as Exit Quit Macroize

RUN

1harm.MSC 28-Jul-1990 16:41:25 NITSIM Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

FILE: Open Save save-As exit Quit Macroize

RUN

4harm.NSC 28-Jul-1998 16:43:31 NITSYN Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

FILE: Open Save save-As eXit Quit Macroize

RUN

8harm.NSC 28-Jul-1998 16:45:18 NITSYN Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

FILE: Open Save save-As exit Quit Macroize

RUN

12harm.MSC 28-Jul-1998 16:48:23 MITSIN Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

```

\ iv4.mpl
\ program to run the 4th
\ independent variable (spectral tilt)

clean
maple.init

\ atom definition

1 -- d:\kathy\nine\iv4\complex1.ss
2 -- complex2
3 -- complex3
4 -- complex4
5 -- complex5
6 -- complex6

pattern
clear.display
    500 msec.wait
    6
    cycles
    from.column 1 #play
    200 msec.silence
    end.cycles
    2000 msec.silence
clear.display
    6
    cycles
    from.column 2 #play
    200 msec.silence
    end.cycles
after.sounds:
    " 1 -- first set sounded more urgent
    " display.text
    " 2 -- second set sounded more urgent
    " display.text
    " 0 -- both sounded equally urgent
    " display.text
    " 6 -- undecided
    " display.text
    response 1 2 6 0 end.response to.column 3
    from.column 3 6 =?
    if.true get.count 1 M+ set.count end.if

end.pattern

read.table iv4.des
1 set.design.table

```

\ iv4.des

```
1 2
1 3
1 4
1 5
1 6
2 3
2 4
2 5
2 6
3 4
3 5
3 6
4 5
4 6
5 6
2 1
3 1
4 1
5 1
6 1
3 2
4 2
5 2
6 2
4 3
5 3
6 3
5 4
6 4
6 5
```

```
! iv4.mcl
! creating a ss file for iv4

create/ss complex1
run complex1 complex1 complex1 .3981

create/ss complex2
run complex2 complex2 complex2 .5623

create/ss complex3
run complex3 complex3 complex3 .2818

create/ss complex4
run complex4 complex4 complex4 .2818

create/ss complex5
run complex5 complex5 complex5 .3981

create/ss complex6
run complex6 complex6 complex6 .3981
```

FILE: Open Save save-As exit Quit Macroize

RUN

complex1.MSC 28-Jul-1998 16:51:17 NITSIM Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

```
\ iv5.mpl
\ program to run the 5th
\ independent variable (pitch)
```

```
clean
maple.init
```

```
\ atom definition
```

```
1 -- d:\kathy\nine\iv5\pitch1.ss
2 -- pitch2
3 -- pitch3
4 -- pitch4
5 -- pitch5
```

```
pattern
clear.display
  500 msec.wait
  6
  cycles
    from.column 1 #play
    200 msec.silence
  end.cycles
  2000 msec.silence
clear.display
  6
  cycles
    from.column 2 #play
    200 msec.silence
  end.cycles
after.sounds:
  " 1 -- first set sounded more urgent
  " display.text
  " 2 -- second set sounded more urgent
  " display.text
  " 0 -- both sounded equally urgent
  " display.text
  " 6 -- undecided
  " display.text
response 1 2 6 0 end.response to.column 3
from.column 3 6 =?
if.true get.count 1 M+ set.count end.if
```

```
end.pattern
```

```
read.table iv5.des
1 set.design.table
```

\ iv5.des

1	2
1	3
1	4
1	5
2	3
2	4
2	5
3	4
3	5
4	5
2	1
3	1
4	1
5	1
3	2
4	2
5	2
4	3
5	3
5	4

! iv5.mcl
! creating a set of stimuli for the
! 5th independent variable (fundamental frequency)

create/ss pitch1.ss
run complex1 complex1 pitch1 .8913

create/ss pitch2.ss
run complex2 complex2 pitch2 .5012

create/ss pitch3.ss
run complex3 complex3 pitch3 .4467

create/ss pitch4.ss
run complex4 complex4 pitch4 .4467

create/ss pitch5.ss
run complex5 complex5 pitch5 .3981

FILE: Open Save save-As eXit Quit Macroize

RUN

complex1.NSC 28-Jul-1998 17:19:59 NITSYN Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

```
\ iv6.mpl
\ this is a program to run the
\ 6th independent variable (fm)
```

```
clean
maple.init
```

```
\ atom definition
```

```
11 -- d:\kathy\nine\iv6\fm1.ss
12 -- fm2
13 -- fm3
14 -- fm4
15 -- fm5
16 -- fm6
```

```
\ Define experimental sequences
```

```
1 SEQUENCE
```

```
11 200 msec.silence
11 200 msec.silence
11 200 msec.silence
11 200 msec.silence
11 200 msec.silence
11 200 msec.silence
end.sequence
```

```
2 SEQUENCE
```

```
12 200 msec.silence
12 200 msec.silence
12 200 msec.silence
12 200 msec.silence
12 200 msec.silence
12 200 msec.silence
end.sequence
```

```
3 SEQUENCE
```

```
13 200 msec.silence
13 200 msec.silence
13 200 msec.silence
13 200 msec.silence
13 200 msec.silence
13 200 msec.silence
end.sequence
```

```
4 SEQUENCE
```

```
14 200 msec.silence
14 200 msec.silence
14 200 msec.silence
14 200 msec.silence
14 200 msec.silence
14 200 msec.silence
end.sequence
```

```
5 SEQUENCE
```

```
15 200 msec.silence
15 200 msec.silence
end.sequence
```

6 SEQUENCE

```
16 200 msec.silence
16 200 msec.silence
end.sequence
```

\ experimental pattern and screen display

pattern

clear.display

```
500 msec.wait
from.column 1 #play
2000 msec.silence
from.column 2 #play
```

after.sounds:

```
" 1 -- first set sounded more urgent
" display.text
" 2 -- second set sounded more urgent
" display.text
" 0 -- both sounded equally urgent
" display.text
" 6 -- undecided
" display.text
response 1 2 6 0 end.response to.column 3
from.column 3 6 =?
if.true get.count 1 M+ set.count end.if
```

end.pattern

```
read.table iv6.des
1 set.design.table
```

\ iv6.des

```
1 2
1 3
1 4
1 5
1 6
2 3
2 4
2 5
2 6
3 4
3 5
3 6
4 5
4 6
5 6
2 1
3 1
4 1
5 1
6 1
3 2
4 2
5 2
6 2
4 3
5 3
6 3
5 4
6 4
6 5
```

```
! iv6.mcl
! program to generate stimuli
! for the 6th independent variable
```

```
create/ss fm1
run newfm 0 0 350 fm1 .4467
```

```
create/ss fm2
run newfm 4 35 350 fm2 .5623
```

```
create/ss fm3
run newfm 8 35 350 fm3 .5623
```

```
create/ss fm4
run newfm 16 35 350 fm4 .5623
```

```
create/ss fm5
run longfm 0 0 350 fm5 .3981
```

```
create/ss fm6
run longfm 4 35 350 fm6 .5012
```

FILE: Open Save save-As eXit Quit Macroize

RUN

longfm.NSC 28-Jul-1998 17:33:38 NITSYN Stream Processor Configuration

FM circuit: FM freq., FM % excursion, Carrier

P1. FM Freq. in Hz

P2. FM excursion in Hz

P3. Carrier Freq.

P4. Output

P5. Attenuator

FILE: Open Save save-As eXit Quit Macroize

RUN

newfm.MSC 28-Jul-1998 17:25:08 NITSYN Stream Processor Configuration

Fm circuit

P1. FM Freq. in Hz

P2. FM excursion in Hz

P3. Carrier Freq.

P4. Output

P5. Attenuator

```

\ iv7.mpl
\ program to run the 7th
\ independent variable (frequency glides)

clean
maple.init

\ atom definition

1 -- d:\kathy\nine\iv7\none.ss
2 -- u
3 -- d
4 -- ud
5 -- du
6 -- udu
7 -- dud

pattern
clear.display
    500 msec.wait
    5
    cycles
    from.column 1 #play
    200 msec.silence
    end.cycles
    2000 msec.silence
    clear.display
    5
    cycles
    from.column 2 #play
    200 msec.silence
    end.cycles

after.sounds:
    " 1 -- first set sounded more urgent
    " display.text
    " 2 -- second set sounded more urgent
    " display.text
    " 0 -- both sounded equally urgent
    " display.text
    " 6 -- undecided
    " display.text
    response 1 2 6 0 end.response to.column 3
    from.column 3 6 =?
    if.true get.count 1 M+ set.count end.if

end.pattern

read.table iv7.des
1 set.design.table

```

\ iv7.des

```
1 2
1 3
1 4
1 5
1 6
1 7
2 3
2 4
2 5
2 6
2 7
3 4
3 5
3 6
3 7
4 5
4 6
4 7
5 6
5 7
6 7
2 1
3 1
4 1
5 1
6 1
7 1
3 2
4 2
5 2
6 2
7 2
4 3
5 3
6 3
7 3
5 4
6 4
7 4
6 5
7 5
7 6
```

! iv7.mcl
! creating a set of ss files to run
! the 7th independent variable (fglides)

create/ss none.ss
run complex none none.ss .5012

create/ss u.ss
run complex u u.ss .5012

create/ss d.ss
run complex d d.ss .5012

create/ss ud.ss
run complex ud ud.ss .5012

create/ss du.ss
run complex du du.ss .5012

create/ss udu.ss
run complex udu udu.ss .5012

create/ss dud.ss
run complex dud dud.ss .5012


```

!none.MLS
w 0 0 0.41 1
N1 0.0375 0.35
N2 0 0.025 1
W0.325
N2 1 0.025 0
W0.075
B99

```

```

!u.MLS
w 0 0 0.41 1
N1 0.035 0.025
N2 0 0.025 1
W0.025
N1 0.035 0.3 0.04
W0.3
N1 0.04 0.025
N2 1 0.025 0
W0.075
B99

```

```

!d.MLS
w 0 0 0.41 1
N1 0.04 0.025
N2 0 0.025 1
W0.025
N1 0.04 0.3 0.035
W0.3
N1 0.035 0.025
N2 1 0.025 0
W0.075
B99

```

```

!ud.MLS
w 0 0 0.41 1
N1 0.035 0.025
N2 0 0.025 1
W0.025
N1 0.035 0.15 0.04
W0.15
N1 0.04 0.15 0.035
W0.15
N1 0.035 0.025
N2 1 0.025 0
W0.075
B99

```

```

!du.MLS
w 0 0 0.41 1
N1 0.04 0.025
N2 0 0.025 1
W0.025
N1 0.04 0.15 0.035
W0.15
N1 0.035 0.15 0.04
W0.15
N1 0.04 0.025
N2 1 0.025 0
W0.075
B99

```

```

!udu.MLS
w 0 0 0.41 1
N1 0.035 0.025
N2 0 0.025 1
W0.025
N1 0.035 0.1 0.04
W0.1
N1 0.04 0.1 0.035
W0.1
N1 0.035 0.1 0.04
W0.1
N1 0.04 0.025
N2 1 0.025 0
W0.075
B99

```

```

!dud.MLS
w 0 0 0.41 1
N1 0.04 0.025
N2 0 0.025 1
W0.025
N1 0.04 0.1 0.035
W0.1
N1 0.035 0.1 0.04
W0.1
N1 0.04 0.1 0.035
W0.1
N1 0.035 0.025
N2 1 0.025 0
W0.075
B99

```

```

\ iv8.mpl
\ program to run the 8th
\ independent variable (envelope shape)

clean
maple.init

\ atom definition

1 -- d:\kathy\nine\iv8\complex1.ss
2 -- complex2
3 -- complex3
4 -- complex4
5 -- complex5
6 -- complex6

\ experimental pattern and screen display

pattern
  clear.display
  500 msec.wait
  5
  cycles
  from.column 1 #play
  200 msec.silence
  end.cycles
  2000 msec.silence
  clear.display
  5
  cycles
  from.column 2 #play
  200 msec.silence
  end.cycles

after.sounds:
  " 1 -- first set sounded more urgent
  " display.text
  " 2 -- second set sounded more urgent
  " display.text
  " 0 -- both sounded equally urgent
  " display.text
  " 6 -- undecided
  " display.text
  response 1 2 6 0 end.response to.column 3
  from.column 3 6 =?
  if.true get.count 1 M+ set.count end.if

end.pattern

read.table iv8.des
1 set.design.table

```

\ iv8.des

```
1 2
1 3
1 4
1 5
1 6
2 3
2 4
2 5
2 6
3 4
3 5
3 6
4 5
4 6
5 6
2 1
3 1
4 1
5 1
6 1
3 2
4 2
5 2
6 2
4 3
5 3
6 3
5 4
6 4
6 5
```

```
! iv8.mcl
! creating a set of ss files to run the 8th
! independent variable (envelope shape)
```

```
create/ss complex1.ss
run complex complex1 complex1 .3981
```

```
create/ss complex2.ss
run complex complex2 complex2 .4467
```

```
create/ss complex3.ss
run complex complex3 complex3 .4467
```

```
create/ss complex4.ss
run complex complex4 complex4 .5012
```

```
create/ss complex5.ss
run complex complex5 complex5 .4467
```

```
create/ss complex6.ss
run complex complex6 complex6 .5623
```

FILE (MLS): Save save-as append Merge exit Quit

RUN

```
!complex1.MLS
w 0 0 0.385 1
N1 0.035 0.325
N2 0 0.025 1
W0.3
N2 1 0.025 0
W0.075
B99
```

FILE (MLS): Save save-as append Merge exit Quit

RUN

```
!complex2.MLS
w 0 0 0.385 1
N1 0.035 0.325
N2 0 0.1 1
W0.225
N2 1 0.1 0
W0.15
B99
```

FILE (MLS): Save save-as append Merge exit Quit

RUN

```
!complex3.MLS
w 0 0 0.385 1
N1 0.035 0.325
N2 0 0.025 1
W0.225
N2 1 0.1 0
W0.15
B99
```

```
!complex4.MLS
w 0 0 0.385 1
N1 0.035 0.325
N2 0 0.025 1
W0.125
N2 1 0.2 0
W0.25
B99
```

```
!complex5.MLS
w 0 0 0.385 1
N1 0.035 0.325
N2 0 0.1 1
W0.3
N2 1 0.025 0
W0.075
B99
```

```
!complex6.MLS
w 0 0 0.385 1
N1 0.035 0.325
N2 0 0.25 1
W0.3
N2 1 0.025 0
W0.075
B99
```

```
\ iv9.mpl
\ program to run the 9th
\ independent variable (pitch steps)
```

```
clean
maple.init
```

```
\ atom definition
```

```
1 -- d:\kathy\nine\iv9\1step.ss
2 -- 2stepsu
3 -- 3stepsu
4 -- 2stepsd
5 -- 3stepsd
```

```
pattern
clear.display
  500 msec.wait
  5
  cycles
    from.column 1 #play
    200 msec.silence
  end.cycles
  2000 msec.silence
clear.display
  5
  cycles
    from.column 2 #play
    200 msec.silence
  end.cycles
```

```
after.sounds:
```

```
" 1 -- first set sounded more urgent
" display.text
" 2 -- second set sounded more urgent
" display.text
" 0 -- both sounded equally urgent
" display.text
" 6 -- undecided
" display.text
response 1 2 6 0 end.response to.column 3
from.column 3 6 =?
if.true get.count 1 M+ set.count end.if
```

```
end.pattern
```

```
read.table iv9.des
1 set.design.table
```


\ iv9.des

```
1 2
1 3
1 4
1 5
2 3
2 4
2 5
3 4
3 5
4 5
2 1
3 1
4 1
5 1
3 2
4 2
5 2
4 3
5 3
5 4
```

```
! iv9.mcl
! creating a set of ss files to run
! the 9th independent variable (pitch steps)
```

```
create/ss 1step.ss
run complex 1step 1step .5012
```

```
create/ss 2stepsu.ss
run complex 2stepsu 2stepsu .4467
```

```
create/ss 3stepsu.ss
run complex 3stepsu 3stepsu .4467
```

```
create/ss 2stepsd.ss
run complex 2stepsd 2stepsd .4467
```

```
create/ss 3stepsd.ss
run complex 3stepsd 3stepsd .4467
```

```

!1step.MLS
w 0 0 0.41 1
N1 0.0375 0.35
N2 0 0.025 1
W0.325
N2 1 0.025 0
W0.075
B99

```

```

!2stepsu.MLS
w 0 0 0.41 1
N1 0.035 0.125
N2 0 0.025 1
W0.125
N1 0.0375 0.1
W0.1
N1 0.035 0.125
W0.1
N2 1 0.025 0
W0.075
B99

```

```

!3stepsu.MLS
w 0 0 0.41 1
N1 0.035 0.085
N2 0 0.025 1
W0.085
N1 0.0375 0.06
W0.06
N1 0.04 0.06
W0.06
N1 0.0375 0.06
W0.06
N1 0.035 0.085
W0.06
N2 1 0.025 0
W0.075
B99

```

```

!2stepsd.MLS
w 0 0 0.41 1
N1 0.0375 0.125
N2 0 0.025 1
W0.125
N1 0.035 0.1
W0.1
N1 0.0375 0.125
W0.1
N2 1 0.025 0
W0.075
B99

```

```

!3stepsd.MLS
w 0 0 0.41 1
N1 0.04 0.085
N2 0 0.025 1
W0.085
N1 0.0375 0.06
W0.06
N1 0.035 0.06
W0.06
N1 0.0375 0.06
W0.06
N1 0.04 0.085
W0.06
N2 1 0.025 0
W0.075
B99

```

Appendix C

This appendix is composed of the software programs used to run Experiment 2.

Below are a list of the suffixes used indicating the type of program.

.mpl indicates a MAPLE program

MAPLE stands for Manager of Auditory Perception and Linguistics Experiments

.des indicates a design table

.mcl indicates a Mitsyn command language program

.mls indicates a Mitsyn low-level score program

.msc indicates a Mitsyn stream processor configuration

.mve indicates a Mitsyn vector file which specifies the power spectrum of the harmonics

```
* ma2p.mpl
* This program runs the practice trial for Experiment 2
* and saves the data to d:\kathy\exp2p\exp2p.dat
```

```
SCREEN.CLEAR
" Hit the <Enter> key when you are ready to start."
KEY DROP
```

```
load d:\kathy\exp2p\exp2p.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\exp2p\exp2p.dat
```

```
SCREEN.CLEAR
" This is the end of the practice trial.
Please inform the experimenter of this."
KEY DROP
```

```
* ma2.mpl
* This is a program to run Experiment 2.
* The data is automatically saved to d:\kathy\exp2r\exp2.dat
```

```
SCREEN.CLEAR
" Hit the <Enter> key when you are ready to start."
KEY DROP
```

```
load d:\kathy\exp2r\exp2.mpl
trials
TRIAL.TABLE SAVE.TABLE d:\kathy\exp2r\exp2.dat
```

```
SCREEN.CLEAR
" That is the end of this part of the experiment.
Please inform the experimenter of this."
KEY DROP
```

```
\ exp2.mpl
\ this is a program to run the
\ 2nd experiment
```

```
clean
maple.init
```

```
\ atom definition
```

```
101 -- d:\kathy\exp2r\No1.ss
102 -- No2
103 -- No3
104 -- No4
105 -- No5
106 -- No6
107 -- No7
108 -- No8
109 -- No9
110 -- No10
111 -- No11
112 -- No12
113 -- No13
114 -- No14
115 -- No15
116 -- No16
117 -- No17
118 -- No18
119 -- No19
120 -- No20
121 -- No21
122 -- No22
123 -- No23
124 -- No24
125 -- No25
126 -- No26
127 -- No27
128 -- No28
129 -- No29
130 -- No30
131 -- No31
132 -- No32
```

```
1 SEQUENCE
  101 50 msec.silence
end.sequence

2 SEQUENCE
  102 50 msec.silence
end.sequence

3 SEQUENCE
  103 50 msec.silence
end.sequence

4 SEQUENCE
  104 50 msec.silence
end.sequence

5 SEQUENCE
  105 50 msec.silence
end.sequence
```

6 SEQUENCE
106 50 msec.silence
end.sequence

7 SEQUENCE
107 50 msec.silence
end.sequence

8 SEQUENCE
108 50 msec.silence
end.sequence

9 SEQUENCE
109 50 msec.silence
end.sequence

10 SEQUENCE
110 50 msec.silence
end.sequence

11 SEQUENCE
111 50 msec.silence
end.sequence

12 SEQUENCE
112 50 msec.silence
end.sequence

13 SEQUENCE
113 50 msec.silence
end.sequence

14 SEQUENCE
114 50 msec.silence
end.sequence

15 SEQUENCE
115 50 msec.silence
end.sequence

16 SEQUENCE
116 50 msec.silence
end.sequence

17 SEQUENCE
117 50 msec.silence
end.sequence

18 SEQUENCE
118 50 msec.silence
end.sequence

19 SEQUENCE
119 50 msec.silence
end.sequence

20 SEQUENCE
120 50 msec.silence
end.sequence

21 SEQUENCE
121 50 msec.silence
end.sequence

22 SEQUENCE
122 50 msec.silence
end.sequence

23 SEQUENCE
123 50 msec.silence
end.sequence

24 SEQUENCE
124 50 msec.silence
end.sequence

25 SEQUENCE
125 50 msec.silence
end.sequence

26 SEQUENCE
126 50 msec.silence
end.sequence

27 SEQUENCE
127 50 msec.silence
end.sequence

28 SEQUENCE
128 50 msec.silence
end.sequence

29 SEQUENCE
129 50 msec.silence
end.sequence

30 SEQUENCE
130 50 msec.silence
end.sequence

31 SEQUENCE
131 50 msec.silence
end.sequence

32 SEQUENCE
132 50 msec.silence
end.sequence

33 SEQUENCE
101 350 msec.silence
end.sequence

34 SEQUENCE
102 350 msec.silence
end.sequence

35 SEQUENCE
103 350 msec.silence
end.sequence

36 SEQUENCE
104 350 msec.silence
end.sequence

37 SEQUENCE
105 350 msec.silence
end.sequence

38 SEQUENCE
106 350 msec.silence
end.sequence

39 SEQUENCE
107 350 msec.silence
end.sequence

40 SEQUENCE
108 350 msec.silence
end.sequence

41 SEQUENCE
109 350 msec.silence
end.sequence

42 SEQUENCE
110 350 msec.silence
end.sequence

43 SEQUENCE
111 350 msec.silence
end.sequence

44 SEQUENCE
112 350 msec.silence
end.sequence

45 SEQUENCE
113 350 msec.silence
end.sequence

46 SEQUENCE
114 350 msec.silence
end.sequence

47 SEQUENCE
115 350 msec.silence
end.sequence

48 SEQUENCE
116 350 msec.silence
end.sequence

49 SEQUENCE
117 350 msec.silence
end.sequence

50 SEQUENCE
118 350 msec.silence
end.sequence

51 SEQUENCE
119 350 msec.silence
end.sequence

52 SEQUENCE
120 350 msec.silence
end.sequence

53 SEQUENCE
121 350 msec.silence
end.sequence

54 SEQUENCE
122 350 msec.silence
end.sequence

55 SEQUENCE
123 350 msec.silence
end.sequence

56 SEQUENCE
124 350 msec.silence
end.sequence

57 SEQUENCE
125 350 msec.silence
end.sequence

58 SEQUENCE
126 350 msec.silence
end.sequence

59 SEQUENCE
127 350 msec.silence
end.sequence

60 SEQUENCE
128 350 msec.silence
end.sequence

61 SEQUENCE
129 350 msec.silence
end.sequence

62 SEQUENCE
130 350 msec.silence
end.sequence

63 SEQUENCE
131 350 msec.silence
end.sequence

64 SEQUENCE
132 350 msec.silence
end.sequence

```
pattern
  clear.display
  500 msec.wait
  from.column 1 cycles
  from.column 2 #play
  end.cycles

  after.sounds:
    "      1 _____ 7" display.text
    "Not urgent          Very Urgent" display.text

    response 1 2 3 4 5 6 7 end.response to.column 3

end.pattern

read.table exp2.des
1 set.design.table
```

\ exp2.des (Design table for randomization of sequences.)

0 1
0 2
0 3
0 4
0 5
0 6
0 7
0 8
0 9
0 10
0 11
0 12
0 13
0 14
0 15
0 16
0 17
0 18
0 19
0 20
0 21
0 22
0 23
0 24
0 25
0 26
0 27
0 28
0 29
0 30
0 31
0 32
4 33
4 34
4 35
4 36
4 37
4 38
4 39
4 40
4 41
4 42
4 43
4 44
4 45
4 46
4 47
4 48
4 49
4 50
4 51
4 52
4 53
4 54
4 55
4 56
4 57
4 58
4 59
4 60
4 61
4 62
4 63
4 64

```
! exp2.mcl
! creating a ss file for the 2nd experiment

create/ss No1
run nu5 g175hz No1 .7943

create/ss No2
run u11 450hz No2 .7079

create/ss No3
run u5 450hz No3 .5623

create/ss No4
run nu11 450hz No4 .7943

create/ss No5
run u11 175hz No5 .8913

create/ss No6
run u11 g450hz No6 .6310

create/ss No7
run nu11 g175hz No7 .7943

create/ss No8
run u5 g175hz No8 1

create/ss No9
run nu5 g450hz No9 .4467

create/ss No10
run nu5 175hz No10 .8913

create/ss No11
run nu5 450hz No11 .5012

create/ss No12
run u5 175hz No12 1

create/ss No13
run u5 g450hz No13 .6310

create/ss No14
run nu11 175hz No14 1

create/ss No15
run nu11 g450hz No15 .6310

create/ss No16
run u11 g175hz No16 .5623

create/ss No17
run nu5 g175hz No17 .1413

create/ss No18
run u11 450hz No18 .1259

create/ss No19
run u5 450hz No19 .1000
```

create/ss No20	
run nu11 450hz No20	.1413
create/ss No21	
run u11 175hz No21	.1778
create/ss No22	
run u11 g450hz No22	.1259
create/ss No23	
run nu11 g175hz No23	.1413
create/ss No24	
run u5 g175hz No24	.1778
create/ss No25	
run nu5 g450hz No25	.0794
create/ss No26	
run nu5 175hz No26	.1585
create/ss No27	
run nu5 450hz No27	.0891
create/ss No28	
run u5 175hz No28	.2239
create/ss No29	
run u5 g450hz No29	.1259
create/ss No30	
run nu11 175hz No30	.1585
create/ss No31	
run nu11 g450hz No31	.1122
create/ss No32	
run u11 g175hz No32	.1122

```

!175hz.MLS
w 0 0 0.31 1
N1 0.0175 0.25
N2 0 0.025 1
W0.225
N2 1 0.025 0
W0.075
B99

```

```

!450hz.MLS
w 0 0 0.31 1
N1 0.045 0.25
N2 0 0.025 1
W0.225
N2 1 0.025 0
W0.075
B99

```

```

!g175hz.mls
w 0 0 0.31 1
N1 0.015 0.025
N2 0 0.025 1
W0.025
N1 0.015 0.1 0.02
W0.1
N1 0.02 0.1 0.015
W0.1
N1 0.015 0.025
N2 1 0.025 0
W0.075
B99

```

```

!g450hz.mls.mls
w 0 0 0.31 1
N1 0.0425 0.025
N2 0 0.025 1
W0.025
N1 0.0425 0.1 0.0475
W0.1
N1 0.0475 0.1 0.0425
W0.1
N1 0.0425 0.025
N2 1 0.025 0
W0.075
B99

```

FILE: Open Save save-As exit Quit Macroize

RUN

nu5.MSC 28-Jul-1990 14:38:38 NITSYN Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

FILE: Open Save save-As eXit Quit Macroize

RUN

nu11.NSC 28-Jul-1998 14:31:57 NITSYN Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

FILE: Open Save save-As eXit Quit Macroize

RUN

u5.NSC 28-Jul-1998 14:33:16 NITSYN Stream Processor Configuration
complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

FILE: Open Save save-As exit Quit Macroize

RUN

u11.NSC 28-Jul-1998 14:34:46 NITSYN Stream Processor Configuration

complex tone of varying freq, amp, and #of harmonics

P1. Score

P2. Output

P3. Attenuator

FILE: Open Save save-Hs exit Quit

RUN

FILE: Open Save save-As exit Quit

RUN

FILE: Open Save save-HS EXIT Quit

RUN

Harmonic weights in decibels

Harmonically constrained vector "nu5"

FILE: Open Save save-As eXit Quit

RUN

Appendix D

Graphs of nine interaction effects and tables of simple main effects of these interactions. 'Lu' in the graphs indicates the low urgency level of the independent variable as determined in Experiment 1. 'Hu' indicates the high urgency level of the independent variable as determined by Experiment 1.

1. Number of harmonics by fundamental frequency interaction.
2. Number of harmonics by frequency glide interaction.
3. Number of harmonics by loudness interaction.
4. Spectral shape by frequency glide interaction.
5. Frequency glide by loudness interaction.
6. Number of harmonics by spectral shape by fundamental frequency interaction.
7. Number of harmonics by frequency glide by fundamental frequency interaction.
8. Number of harmonics by loudness by fundamental frequency interaction.
9. Frequency glide by spectral shape by fundamental frequency interaction.

1. Number of Harmonics x Fundamental Frequency Interaction

Significant Simple Main Effects	F-ratio	df	p
#harmonics at Hu Fo	90.972	1, 39	<.0001
Fo at Lu #harmonics	26.928	1, 39	<.0001

At $p < .001$, the number of harmonics (#harmonics) at the 'low urgency' (Lu) level of fundamental frequency (Fo) were not significant and neither was the simple main effect of fundamental frequency at the 'high urgency' level (Hu) of the '#harmonics' independent variable.

Figure D1. Number of harmonics x fundamental frequency interaction

2. Number of Harmonics x Frequency Glide Interaction

Significant Simple Main Effects	F-ratio	df	p
#harmonics at Hu Fglide	60.995	1, 39	<.0001
Fglide at Hu #harmonics	59.818	1, 39	<.0001
Fglide at Lu #harmonics	28.938	1, 39	<.0001

At $p < .001$, the number of harmonics (#harmonics) at the 'low urgency' (Lu) level of frequency glide (Fglide) were not significant.

Figure D2. Number of harmonics x frequency glide interaction

3. Number of Harmonics x Loudness Interaction

Significant Simple Main Effects	F-ratio	df	p
#harmonics at Hu Loudness	34.180	1, 39	<.0001
Loudness at Hu #harmonics	193.786	1, 39	<.0001
Loudness at Lu #harmonics	176.623	1, 39	<.0001

At $p < .001$, the number of harmonics (#harmonics) at the 'low urgency' (Lu) level of loudness were not significant.

Figure D3. Number of harmonics x loudness interaction

4. Spectral Shape x Frequency Glide Interaction

Significant Simple Main Effects	F-ratio	df	p
Spectral shape at Hu Fglide	78.813	1, 39	<.0001
Spectral shape at Lu Fglide	109.310	1, 39	<.0001
Fglide at Hu spectral shape	30.935	1, 39	<.0001
Fglide at Lu spectral shape	65.323	1, 39	<.0001

Figure D4. Spectral shape x frequency glide interaction

5. Frequency Glide (Fglide) x Loudness Interaction

Significant Simple Main Effects	F-ratio	df	p
Fglide at Hu Loudness	52.244	1, 39	<.0001
Fglide at Lu Loudness	33.564	1, 39	<.0001
Loudness at Hu Fglide	222.624	1, 39	<.0001
Loudness at Lu Fglide	144.629	1, 39	<.0001

Figure D5. Frequency glide (Fglide) x loudness interaction

6. Number of Harmonics x Spectral Shape x Fundamental Frequency Interaction

Significant Simple Main Effects	F-ratio	df	p
#harmonics at Hu Shape/Hu Fo	56.903	1, 39	<.0001
#harmonics at Lu Shape/Hu Fo	81.892	1, 39	<.0001
#harmonics at Lu Shape/Lu Fo	13.305	1, 39	<.001
Spectral shape at Hu Harms/Hu Fo	63.264	1, 39	<.0001
Spectral shape at Hu Harms/Lu Fo	72.990	1, 39	<.0001
Spectral shape at Lu Harms/Hu Fo	88.595	1, 39	<.0001
Spectral shape at Lu Harms/Lu Fo	28.688	1, 39	<.0001
Fo at Hu Harms/Lu Shape	12.541	1, 39	<.001
Fo at Lu Harms/Hu Shape	12.335	1, 39	<.001
Fo at Lu Harms/Lu Shape	35.094	1, 39	<.0001

- * #harmonics = Number of harmonics = Harms
 Shape = Spectral shape
 Fo = Fundamental frequency
 Hu = 'high urgency' level of that independent variable
 Lu = 'low urgency' level of that independent variable

At $p < .001$, the fundamental frequency (fo) at the 'high urgency' (Hu) level of the number of harmonics variable and 'high urgency' level of spectral shape was not significant.

Figure D6. Number of harmonics x spectral shape x fundamental frequency interaction

7. Number of Harmonics x Frequency Glide x Fundamental Frequency Interaction

Significant Simple Main Effects	F-ratio	df	p
#harmonics at Hu Fglide/Hu Fo	104.299	1, 39	<.0001
#harmonics at Hu Fglide/Lu Fo	45.420	1, 39	<.0001
#harmonics at Lu Fglide/Lu Fo	43.190	1, 39	<.0001
Fglide at Hu Harms/Hu Fo	50.097	1, 39	<.0001
Fglide at Hu Harms/Lu Fo	63.742	1, 39	<.0001
Fglide at Lu Harms/Hu Fo	37.809	1, 39	<.0001
Fglide at Lu Harms/Lu Fo	19.712	1, 39	<.0001
Fo at Hu Harms/Lu Fglide	16.201	1, 39	<.0001
Fo at Lu Harms/Hu Fglide	15.885	1, 39	<.0001
Fo at-Lu Harms/Lu Fglide	34.264	1, 39	<.0001

- * #harmonics = Number of harmonics = Harms
- Fglide = Frequency glide
- Fo = Fundamental frequency
- Hu = 'high urgency' level of that independent variable
- Lu = 'low urgency' level of that independent variable

At $p < .001$, two of the simple main effects were not significant:

The number of harmonics at the 'low urgency' (Lu) level of the fundamental frequency and 'high urgency' (Hu) level of the frequency glide variable was not significant.

The fundamental frequency (fo) at the 'high urgency' (Hu) level of the number of harmonics variable and 'high urgency' level of frequency glide was not significant.

Figure D7. Number of harmonics x frequency glide x fundamental frequency interaction

8. Number of Harmonics x Loudness x Fundamental Frequency Interaction

Significant Simple Main Effects	F-ratio	df	p
#harmonics at Hu Loudness/Hu Fo	88.570	1, 39	<.0001
#harmonics at Lu Loudness/Hu Fo	31.517	1, 39	<.0001
Loudness at Hu Harms/Hu Fo	193.229	1, 39	<.0001
Loudness at Hu Harms/Lu Fo	173.872	1, 39	<.0001
Loudness at Lu Harms/Hu Fo	149.451	1, 39	<.0001
Loudness at Lu Harms/Lu Fo	182.014	1, 39	<.0001
Fo at Hu Harms/Lu Loudness	14.667	1, 39	<.0001
Fo at Lu Harms/Hu Loudness	19.031	1, 39	<.0001
Fo at Lu Harms/Lu Loudness	27.416	1, 39	<.0001

- * #harmonics = Number of harmonics = Harms
- Fo = Fundamental frequency
- Hu = 'high urgency' level of that independent variable
- Lu = 'low urgency' level of that independent variable

At $p < .001$, three of the simple main effects were not significant:

The number of harmonics at the 'low urgency' (Lu) level of the fundamental frequency at both levels of the loudness were not significant.

The fundamental frequency (fo) at the 'high urgency' (Hu) level of the number of harmonics variable and 'low urgency' level of loudness was not significant.

Figure D8. Number of harmonics x loudness x fundamental frequency interaction

9. Frequency Glide x Spectral Shape x Fundamental Frequency Interaction

Significant Simple Main Effects	F-ratio	df	p
Fglide at Hu Shape/Hu Fo	24.714	1, 39	<.0001
Fglide at Hu Shape/Lu Fo	34.783	1, 39	<.0001
Fglide at Lu Shape/Hu Fo	75.039	1, 39	<.0001
Fglide at Lu Shape/Lu Fo	51.086	1, 39	<.0001
Shape at Hu Fglide/Hu Fo	50.144	1, 39	<.0001
Shape at Hu Fglide/Lu Fo	41.390	1, 39	<.0001
Shape at Lu Fglide/Hu Fo	106.818	1, 39	<.0001
Shape at Lu Fglide/Lu Fo	55.321	1, 39	<.0001

- * Fglide = Frequency glide
- Shape = Spectral shape
- Fo = Fundamental frequency
- Hu = 'high urgency' level of that independent variable
- Lu = 'low urgency' level of that independent variable

At $p < .001$, none of the four simple main effects for fundamental frequency were significant.

Figure D9. Frequency glide x spectral shape x fundamental frequency interaction

Appendix E

This appendix demonstrates the relationship, in graphical form, between the levels of the harmonics programmed into MITSYN (the software used for generating the sounds in the experiments) and the level of the harmonics measured 1 meter from the speaker. These acoustic measurements were made with the sounds played at the same decibel level as they were played in the experiment. For Experiment 2, the acoustic measurements were made with the levels at 90 dB(D). Acoustic measurements were made with a AKG D330BT dynamic microphone connected to a Rockland FFT 512/S Real-Time Spectrum Analyzer.

The first five graphs correspond to the spectral shapes used in Experiment 1 (Independent Variable number 4). Figures E6 to E13 correspond to the spectral shapes used in Experiment 2. Figure E14 is a graph of the frequency response of the system used in the experiments measured 1 meter from the speaker.

* Lu stands for 'low-urgency' level, Hu stands for 'high urgency' level.

Figure E1. Complex 1 spectrum analysis

Figure E2. Complex 2 spectrum analysis

Figure E3. Complex 3 spectrum analysis

Figure E4. Complex 4 spectrum analysis

Figure E5. Complex 5 spectrum analysis

Figure E6. Lu spectral shape, 5 harmonics, Fo 175 Hz

Figure E7. Hu spectral shape, 5 harmonics, Fo 175 Hz

Figure E8. Lu spectral shape, 5 harmonics, Fo 450 Hz

Figure E9. Hu spectral shape, 5 harmonics, Fo 450 Hz

Figure E10. Lu spectral shape, 11 harmonics, Fo 175 Hz

Figure E11. Hu spectral shape, 11 harmonics, Fo 175 Hz

Figure E12. Lu spectral shape, 11 harmonics, Fo 450 Hz

Figure E13. Hu spectral shape, 11 harmonics, Fo 450 Hz

Figure E14. Frequency response of sound system