PERCEPTION OF URGENCY AND ALARM DESIGN

A. GUILLAUME*, C. DRAKE**, M. RIVENEZ**, L. PELLIEUX*, V. CHASTRES*

* Institut de Médecine Aérospatiale du Service de Santé des Armées
BP 73 91223 Brétigny sur Orge Cedex France
aguillaume@imassa.fr
** Laboratoire de Psychologie Expérimentale
Institut de Psychologie, Université Paris V
71, avenue Edouard Vaillant 92774 Boulogne-Billancourt France

Abstract

Psychophysical approaches to urgency perception have identified acoustical properties modulating the perceived degree of urgency. However acoustical properties seemed less efficient in inducing perception of urgency when subjects were under high workload. The aim of the first experiment was to confirm, with a multidimensional approach, the validity of the acoustic parameters in urgency perception described by Edworthy et al. [1]. The aim of the second experiment was to generalize the results obtained to real alarms. The multidimensional scaling approach confirmed the important role of acoustic properties of the alarms in the case of the artificial alarms of Experiment 1, but not with the real alarms of Experiment 2. The generation of alarms using only psychophysical tools cannot be generalized. The mental representation of the sequence probably interacts with the acoustical properties. This should have implications for alarm design.

INTRODUCTION

An alarm should not be created out of its justification and its auditory environment. A house-breaking alarm can be excessively loud and aversive since the aim of the alarm is to induce flight. In the work environment, when dysfunction occurs, alarms have to distract the operator from his main task and induce a shift of his attention to the warning signal without being too disturbing. Furthermore, it must be a source of efficient information. Two kinds of information are involved:

- information about the real degree of urgency which may be conveyed by modulations in the acoustic properties of alarms.
- information about the cause of dysfunction that has unlocked the alarm by use of adapted auditory icons.

A well-adapted alarm increases the probability of an efficient reaction of the operator and decreases reaction time. However, numerous warning systems are non-optimal. Many alarms are too loud and confusing. The "better safe than sorry" principle makes these alarms more useless than useful. Patterson [2] proposed to create alarms with silences between bursts of sounds allowing listeners to think, communicate and react efficiently without being dominated by the idea of turning off the alarm. In urgency estimation, intensity level undoubtedly plays a major role: the louder a warning signal, the greater the urgency estimation. Unfortunately in the noisy environments usually associated with the use of alarms, background noise level is often high and so the potential range over which this parameter can be varied is limited (too low it won't be heard, too high it will be painful and distracting). So, whereas intensity is a dominant factor, it is usually advisable to control it systematically in experimental situations if other parameters are to be identified. This approach is adopted here.

Using psychophysics, Edworthy et al. [1] and Hellier et al. [3] defined the acoustic properties for which modulations induced different degrees of urgency: the faster the rate, the higher the pitch, and the more irregular the harmonics, the greater the perceived urgency. However, Burt et al. [4] showed that perception of urgency with such alarms was greatly impaired under high workload. The aims of the present study were to confirm, with a multidimensional approach, the validity of the acoustic parameters in urgency perception described by Edworthy et al. (1991) and to see to what extent these results can be generalized to real alarms. The question was to know if cognitive parameters were involved. This should have implications for alarm design. Experiment 1 involved sequences created according to Edworthy's principles, Experiment 2 involved real alarms recorded on military aircraft.

EXPERIMENT 1

AIMS

The first aim of this experiment was to confirm, with a multidimensional approach, the validity of the acoustic parameters in urgency perception described by Edworthy. The second aim was to test Edworthy's assumption that the perception of urgency is highly dependent on the acoustic properties of the sequences.

Table 1: acoustic properties of the 13 sequences

S	IOI (ms)	Average pitch (Hz)	pitch range (Hz)	Pulse duration (ms)	harmonic regularity	delayed harmonics	rhythm	pitch contour	Onset ramp (ms)	Offset ramp (ms)
1	150	600	300	150	random	absent	regular	random	20	20
2	175	585	230	150	10% irregular	absent	regular	random	20	20
3	200	510	280	150	random	present	speeding	random	130	20
4	225	525	200	150	10% irregular	present	regular	up/down/up	130	20
5	250	500	275	150	50% irregular	absent	syncopated	down/up x2	20	20
6	275	450	100	200	10% irregular	absent	speeding	up/down/up	20	20
7	300	400	125	150	50% irregular	present	syncopated	up/down	20	20
8	325	335	170	200	50% irregular	absent	regular	down/up	20	180
9	350	300	120	200	regular	present	syncopated	up	20	180
10	375	250	75	200	regular	absent	regular	down/up	20	180
11	400	210	80	200	regular	present	syncopated	down	20	180
12	450	175	50	200	regular	absent	slowing	up/down	180	20
13	550	290	75	200	regular	absent	slowing	down	180	20

One way of confirming this hypothesis is to compare the geometrical perceptual spaces obtained for judgements based on dissimilarity and urgency. Dissimilarity judgements can only be based on the acoustic properties of the sequences. So, if similar spaces are obtained for the two sets of judgements, we will conclude that the urgency judgements are also strongly determined by the acoustic properties of the sequences.

METHOD

Thirteen alarm sequences were synthesized following Edworthy’s principles in order to induce an increasing perceived urgency level. Participants listened to pairs of sequences. They judged the relative perceived urgency and/or the degree of dissimilarity between the two. Group 1 did only dissimilarity judgements without reference to urgency, and Group 2 did both dissimilarity and urgency judgements. Multidimensional scaling was applied to the data, and we attempted to link the dimensions of the perceptual spaces to the acoustical properties of the sequences.

RESULTS

In both perceptual spaces, the weight accorded to Dimension 1 was high whereas those accorded to Dimensions 2 and 3 were very low. These Dimensions 1 were highly correlated ($r=.948$, $p<.0001$). The sequences could be categorized into three clusters: low, medium, and high urgency level in both spaces. Incremental stepwise multiple regressions were carried out on Dimensions 1. Four of the studied acoustical parameters contributed significantly. Together (pitch range, temporal envelope, harmonic regularity and rate), they accounted for 94.8 % of the variance ($p < 0.0001$). Furthermore, the observed urgency judgements were highly correlated with the theoretical urgency judgements ($r = 0.94$, $p< 0.0001$), confirming that, within this set of alarms, the sequences can indeed be ranked from very urgent to not urgent at all.

DISCUSSION

Our results provide support for Edworthy's hypotheses. The multidimensional scaling revealed that the very dominant Dimension 1 was highly correlated with both the theoretical and observed urgency ranking. Further analyses identified which acoustical characteristics were linked to this dimension. As would be expected from the design principles, most of the acoustic parameters co-varied systematically with perceived urgency level: the sequences perceived as the most urgent were fast, had a high pitch varying temporally in a random way, irregular harmonics and a fast onset ramp. The less urgent sequences had a low rate, a quite low pitch progressively falling over time, regular harmonics and slow onsets. Thus, our experimental paradigm revealed similar results to those of Edworthy and consequently validated our method.

The second aim was to test Edworthy’s assumption that urgency perception is highly dependent on the acoustic properties of the alarms. We did this by comparing the perceptual space obtained with dissimilarity judgements (the reference Group 1) with the perceptual space obtained for judgements based on urgency (Group 2). The dissimilarity perceptual space could only be based on the acoustical properties of the sequences. High correlation between the judgements of the two groups would imply that the urgency judgements were also strongly determined by the acoustical properties. So for the sequences studied in Experiment 1, the acoustical characteristics determined the perception of urgency.

EXPERIMENT 2

AIMS

The aim of the second experiment was to see whether the same dimensions and associated acoustic properties can be identified in the case of real alarms.

METHOD

We applied the methodology developed in Experiment 1 to the case of real alarms recorded on military aircraft. Group 1 did only dissimilarity judgements without reference to urgency or alarm, and Group 2 did both dissimilarity and urgency judgements. Multidimensional scaling was applied to the data, and we attempted to link the dimensions of the perceptual spaces to the acoustical properties of the sequences (table 2).

RESULTS

Comparing the dimensions of the perceptual spaces of Group 1 with those of Group 2, the correlation of the dimensions of the two groups was relatively low: for Dimension 1 Group 1 and Group 2, $r = 0.56$, $p<0.0017$ and for Dimension 2 Group 1 and Group 2, $r = 0.55$, $p<0.0004$. For Group 2, the coordinates on Dimension 1 were highly correlated with the urgency rank ordering ($r = 0,989$; $p < 0.0001$). Three clusters were distinguished: high, moderate and low urgency levels. The sequences were distributed along Dimension 1 with an opposition between the alternating sequences perceived as very urgent, and the other sequences ($p=0.0046$).

The three clusters were not individualized in the perceptual space of Group1 (difference judgement).

Table 2: acoustic properties of the 35 sequences

S	Fundamental frequency (Hz)	IOI (ms)	harmonic structure	kind of sequence	onset (ms)	offset (ms)	Roughness (3s, 70 Hz)
1	510	832	odd	intermittent	<1	12	0.17
2	830	3 545	regular	intermittent	<1	420	0.31
3	245	806	odd	intermittent	<1	2	0.19
4	830	400	irregular	intermittent	<1	9	1.33
5	965	n/a	regular	continuous	n/a	n/a	1
6	1200 / 3200	102	odd	alternating	n/a	n/a	0.72
7	1200	101	odd	intermittent	<1	4	0.49
8	1800	179	odd	intermittent	<1	<1	0.73
9	600	327	odd	intermittent	<1	3	0.26
10	2740	233	odd	intermittent	3	13	0.04
11	258	n/a	irregular	continuous	n/a	n/a	1.14
12	430	n/a	irregular	continuous	n/a	n/a	0.26
13	795 / 985	507	regular	alternating	n/a	n/a	0.19
14	580	n/a	regular	continuous	n/a	n/a	0.71
15	480	1030	regular	intermittent	<1	4	0.21
16	25	4234	regular	intermittent	<1	52	1.9
17	3145	235	regular	intermittent	24	118	0.12
18	3125	n/a	regular	continuous	n/a	n/a	0.31
19	400 to 800	3070	sweep every 100 ms	spectral sweep	<1	14	0.7
20	295	2309	regular	intermittent	<1	410	0.25
21	320	n/a	regular	continuous	n/a	n/a	0.12
22	450	n/a	regular	continuous	n/a	n/a	0.03
23	2720 / 325	1290	regular	alternating	n/a	n/a	0.28
24	325	1267	regular	intermittent	24	75	0.22
25	250	859	regular	intermittent	<1	20	0.18
26	800	405	regular	intermittent	<1	63	1.39
27	1670	202	regular	intermittent	<1	44	1.13
28	230	n/a	regular	continuous	n/a	n/a	0.13
29	2400	n/a	regular	continuous	n/a	n/a	0.01
30	850 to 2900	1000	sweep every 1000 ms	spectral sweep	n/a	n/a	0.29
31	230	480	regular	intermittent	<1	24	0.92
32	560 / 625	260	regular	alternating	n/a	n/a	0.29
33	noise (10-350)	n/a	irregular	continuous	n/a	n/a	1.04
34	400	375	regular	intermittent	15	40	0.33
35	500	2459	regular	intermittent	15	37	0.12

DISCUSSION

The perceptual spaces of both Groups differ from one another in the distribution of alarms. The perceptual space obtained with Group 1 is supposed to be entirely described by the acoustical properties of the sequences as in Experiment 1. Compared with the one obtained with Group 2, there are some similarities in the global repartition of the sequences but also major differences in the fact that particular sequences were placed around sequences similar in acoustical properties but with a very different level of urgency. This explains the lower correlation of the dimensions of the perceptual spaces of the two groups. This observation indicates the fact that parameters different from physical properties may interact in the judgement of urgency. Whereas the temporal structure appears to be an important factor, acoustical properties cannot entirely explain the perception of urgency. The concept of a mental representation associated with some alarms provides interesting insights. The results of Experiment 2 could be explained by the fact that mental representations recalled by several auditory sequences outweighed the input of the acoustical properties of the sequence.

GENERAL DISCUSSION

Previous psychophysical approaches have considered the role played by auditory cues in order to create alarms with an increased degree of urgency. In Experiment 1, we also found that acoustical characteristics may be modulated to express more or less urgency in alarms. However, this approach is not sufficient to explain the results of Experiment 2. The perception of urgency is linked with the notion of danger which implies a mental representation of the danger. The alarm would trigger off an alert reaction, shifting attention from the main task to the situation of danger. The judgement of urgency would be the consequence of a mental representation of the cause of the alarm in a particular context, inducing the operator to react. Difficulties in defining an alarm involves finding the more direct link between alarms and their causes or their mental representations in order to limit the attention requirement of listeners to decode the signal; that means to optimize the cognitive resources of the subject while informing him of a danger. Acculturation seems to be a very important factor to take into account. In this way, we emphasize the importance of auditory learning.

In professional activities, learning of several alarms would enhance or strengthen mental representations associated with the alarm concept. Sounds will often be associated to a precise event and to its urgency level. This allows fast and adapted reactions. Schematically, abstract warning signals might convey a certain degree of urgency by modulations of the acoustical properties of alarms. But the link with urgency is precarious [4]. This link could be improved by increasing the link between alarms and their causes or their mental representations. Cognitive influences should be used to design the alarms, that is, the way that the auditory icons could be used as alarms. However for the representational alarms or auditory icons, it is important to take learning into account because the link with the cause is easier [5] but the sequence in itself does not evoke danger in everyday life. Learning leads the listener to focus his attention on the sequence and to prepare his reaction. This link between the sequence and alarm notion or urgency will be reinforced during learning, since the link with the cause is obvious. Conversely, the abstract alarms lack of a link with the cause but have strong link with urgency. Learning should consist in obtaining a more direct link between the alarm and its significance. This means to fit each abstract warning signal with the cause of the alarm. In both cases, the link between the sequence and the cause is less direct than in the everyday environment and it requires more attention. Learning reinforces this link. The stronger the link, the less attention required.

CONCLUSION

Auditory sequences can be categorized according to their perceived degree of urgency. However, judgement is based on two sets of cues: low level ones correspond to acoustical properties as studied by Edworthy et al. [1] and high level ones involving mental representations which are highly dependant on acculturation.

BIBLIOGRAPHIE

[1] J. Edworthy, Loxley, S., & Dennis, L., Improving auditory warning design: relationship between warning sound parameters and perceived urgency, *Human Factors*, vol. 33, pp 205-231, 1991.

[2] R.D. Patterson, Auditory warning sounds in the work environment, *Phil. Trans. R. Soc. Lond.*, vol. 327, pp. 485-492, 1990.

[3] E.J. Hellier, Edworthy J., & Dennis I., Improving auditory warning design : quantifying and predicting the effects of different warning parameters on perceived urgency, *Human Factors*, vol. 35, no. 4, pp. 693-706, 1993.

[4] J.L. Burt, Bartolome, D.S., Burdette, D.W., & Comstock, J.R., A psychophysiological evaluation

of the perceived urgency of auditory warning signals. *Ergonomics*, vol. 38, no. 11, pp. 2327-2340, 1995.
[5] R. Graham, Use of auditory icons as emergency warnings: evaluation within a vehicle collision avoidance application, *Ergonomics*, vol. 42, no. 9, pp.1233-1248, 1999.