Learning and Retention of Auditory Warnings

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ABSTRACT

Auditory warnings are used in a variety of settings such as hospitals and the cockpits of modern military aircraft. This paper describes a study in which sets of auditory warnings comprised of speech, auditory icons (environmental sounds) and abstract sounds were compared with respect to ease of learning and retention. Speech warnings and auditory icons were learnt and retained with equal ease, while abstract-sound warnings were found to be learnt and retained with far greater difficulty.

Keywords

auditory warnings, learning and retention, auditory icons, abstract sounds

INTRODUCTION

Auditory warnings are used in a variety of settings to convey critical information. In modern military aircraft, for example, the auditory modality is used to inform operators about dangerous or potentially dangerous conditions such as low altitude or the presence of a military threat (1). Auditory warnings are also widely used in hospitals to alert staff to equipment malfunctions and the existence of potentially harmful medical conditions.

Two types of sound have most commonly been used as auditory warnings: speech and abstract sound such as simple tones. Speech warnings have the advantages of being suitable for conveying complex information and requiring little or no learning. If the environment in which they are to be used, however, contains a high level of background speech, they may be susceptible to masking. The transmission of speech messages may also require a relatively long period of time. Speech warnings have been recommended for use in situations where the number of alternative warnings is large and the operator is not required to make a particularly rapid response (2). Abstract sounds, on the other hand, are less likely to be masked by background speech and are capable of conveying information more quickly. Their primary disadvantage is the difficulty associated with learning and remembering large warning sets (3, 4, 5). As a result, it has been recommended that sets of abstract sound warnings be restricted in size to a maximum of from five to eight (2, 6).

Another type of sound with potential for use as an auditory warning is environmental sound. This sound type differs from abstract sound in that it is associated with real, or everyday, events (7). Environmental sounds, which we refer to as auditory icons (8), share the advantages of abstract non-speech sounds but are not as limited with respect to the set size that can be learnt. Lawrence and Banks (9) and Lawrence et al. (10), for example, have shown that memory capacity for environmental sounds is probably not exceeded in the case of a 194-item set. The relative ease with which environmental sounds can be remembered appears to result in part from the ease with which they can be assigned verbal labels (11).

This paper describes a study in which the ease of learning and retention of sets of auditory warnings comprised of speech, abstract sounds and auditory icons were compared. This comparison provides one measure of the relative suitability of these sounds for use as auditory warnings.

METHOD

Subjects

Eighteen unpaid subjects, fourteen males and four females, ranging in age from 24 to 45 years were recruited from staff and students at Swinburne University of Technology and the Aeronautical and Maritime Research Laboratory.

Auditory Warnings

For each type of auditory warning a set of eight examples were generated that could be used to represent events that may occur in a military aircraft cockpit. These included seven threat warnings that may be associated with a radar warning receiver and one advisory message that may be associated with self-protection counter measures equipment (see Table 1).

Speech sounds were created synthetically by DECtalk V4.2 (Digital Equipment Corporation), which utilises text-to-speech technology. The voice used was the adult male default voice (Paul) at a speech rate of 180 words/minute, with an average pitch of 120 Hz and a pitch range of 100 Hz. The choice of terms used for the speech warnings was determined by interviewing Royal Australian Air Force (RAAF) aircrew.

Auditory icons were environmental sounds that, where possible, were selected on the basis of a strong relationship between the sound and the event it was associated with. For example, for the threat event “Anti-aircraft Artillery” a gun sound was used. During the design of the auditory icons a number of candidates were generated for each event. These candidates were then demonstrated to aircrew and the one regarded by the majority of aircrew as being the most suitable for each event was chosen. At the end of this process the relationship between the sound and the event was stronger for some events than others (see Table 1). No attempt was made to ensure subjects were aware of any of these relationships and their level of awareness in this regard was not monitored.

The abstract sounds were pulses of synthetic complex sound that varied in both the frequency and time domains and had been designed for maximum discriminability as detailed by Patterson (2). The pulses were 100-150 ms in duration with onsets and offsets of 20-30 ms duration. Each sound consisted of five or more pulses in a distinctive temporal pattern. Spectral components were primarily between 0.5-5.0 kHz with four or more harmonically related components and the fundamental harmonics in the range of 150-1000 Hz. The abstract sounds were randomly assigned to events.

Table 1. Speech and auditory icon sets used in this experiment

Event	Speech	Auditory Icons
Ship	“Boat”	Fog horn
Air Interceptor	“Fighter”	Bird of prey attack call
Anti-Aircraft Artillery	“Guns”	Machine gun firing
Missile Launch	“Launch”	Monkey Screech
Surface to Air Missile	“Missile”	Arrow
Search Radar	“Search”	Sonar beep
Unknown Threat	“Unknown”	Bird territorial call
Chaff Dispensed	“Chaff”	Camera flash & Windchimes

Procedure

Each subject participated in nine experimental sessions conducted over a period of three weeks. For each of the three auditory warning types, subjects were tested on three separate days: initially on Day 1 and again two (Day 3) and seven (Day 8) days later. The initial experimental session on Day 1 consisted of several trials, each of which consisted of two phases: a learning phase and a test phase. In the learning phase, each of the eight warnings was played to the subject over a set of headphones and the name of the event that was to be associated with it was indicated on a computer monitor. The subject was asked to acknowledge each association by pressing a computer keyboard function key labelled with the name of the appropriate event. On completion of the learning phase, the subject proceeded to the test phase where each of the eight warnings was presented without the name of the event being indicated. The subject was required to identify the event associated with each warning and press the corresponding function key. Subjects were instructed to respond as accurately as possible. At the end of each test, the percentage correct out of eight was presented to the subject on the computer monitor. Trials were repeated until the subject achieved a criterion level of proficiency set at 100 percent correct on two consecutive trials. The sessions on Days 3 and 8 differed from that on Day 1 in that the learning phase was deleted from the first trial, which resulted in the sessions beginning with a test phase. This allowed the extent to which the subject had retained the learned associations between warnings and events to be determined.

For each session, two correlated measures of performance were calculated: number of trials required to reach criterion performance and number of errors made during those trials. A non-parametric statistical test, the Friedman Two-Way Analysis of Variance by Ranks with correction for ties, was used to test for significant differences in subject performance across the three sound types on each of Days 1, 3 and 8.

RESULTS

Trials to criterion

The average number of trials required to reach criterion performance for the three sets of auditory warnings on each of Days 1, 3 and 8 are shown in Figure 1. Performance on Day 1 provides an indication of the ease with which the specified associations were learnt, while that on Days 3 and 8 reveals the extent to which the associations were retained.

Day 1

It is evident that the speech auditory warnings were learnt most readily, requiring an average of 2.1 trials. As the minimum possible number of trials in which criterion could be reached was 2, this represents almost perfect performance. The auditory icons were learnt slightly less readily, requiring an average of 3.4 trials, and the abstract sounds proved much more difficult to learn, requiring an average of 8 trials. Analysis of the average number of trials required to reach criterion on Day 1 provided evidence of a significant difference across auditory warning type ($Fr(2)=37.26$, $p<.05$). Further analysis involved comparisons of the differences between individual pairs of auditory warning types. The first of these comparisons indicated that there was a significant difference between the average number of trials required to reach criterion for abstract sounds and icons ($D=19$, $p<.05$). A second comparison, between abstract sounds and speech, also identified a significant difference ($D=22.5$, $p<.05$). However, there was no significant difference between the average number of trials required to reach criterion for speech and icons.

Figure 1. Trials to criterion (N=18)

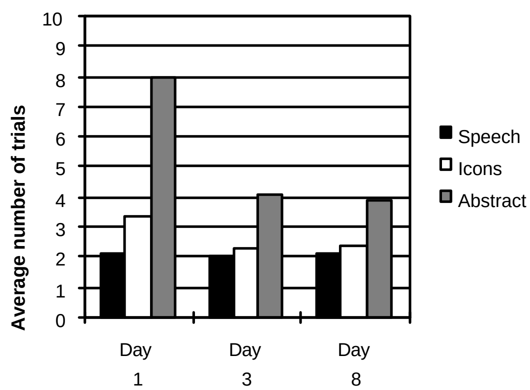
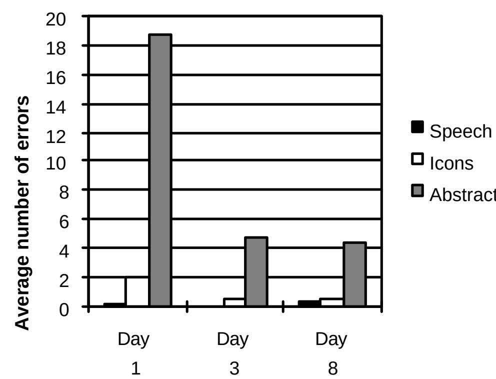


Figure 2. Errors to criterion (N=18)



Days 3 and 8

The results for Days 3 and 8 show that the learned associations between sounds and events were retained almost perfectly for speech and icons. For abstract sounds, however, some re-learning was needed on both days, although the average number of trials required to reach criterion on each day was markedly less than that on Day 1. Analysis of the average number of trials required to reach criterion on Day 3 provided evidence of a significant difference across auditory warning type ($Fr(2)=23.63$, $p<.05$). This was also the case for Day 8 ($Fr(2)=14.1$, $p<.05$). Comparisons of the differences between individual pairs of auditory warning types revealed a significant difference between the average number of trials required to reach criterion for abstract sounds and icons on each of Days 3 ($D=18$, $p<.05$) and 8 ($D=16$, $p<.05$). They also showed significant differences for abstract sounds and speech (Day 3, $D=22.5$, $p<.05$; Day 8, $D=19.5$, $p<.05$). However, there was no significant difference between the average number of trials required to reach criterion for speech and icons on either day.

Errors to criterion

The average number of errors made while reaching criterion performance for each of the three sets of auditory warnings on each of Days 1, 3 and 8 are shown in Figure 2. It can be seen that the pattern of the data in this figure is similar to that in Figure 1.

Day 1

Results on Day 1 again highlight the greater difficulty subjects experienced while learning associations between abstract sounds and events in comparison to speech or icons. Analysis of the average number of errors made in reaching criterion on Day 1 provided evidence of a significant difference across auditory warning type ($Fr(2)=32.36$, $p<.05$). Further analysis revealed significant differences between the number of errors made in reaching criterion for abstract sounds and icons ($D=22$, $p<.05$) and abstract sounds and speech ($D=33$, $p<.05$). However, there was no significant difference between the number of errors made in reaching criterion for speech and icons.

Days 3 and 8

On Days 3 and 8 the average number of errors made for speech and icons were negligible, again demonstrating that associations between these sound types and events were retained almost perfectly. For abstract sounds, however, the average number of errors were markedly greater, reflecting a need for re-learning. Analysis of the average number of errors made while reaching criterion provided evidence of a significant difference across auditory warning type on each of Days 3 ($Fr(2)=23.63$, $p<.05$) and 8 ($Fr(2)=24.6$, $p<.05$). Further analysis revealed significant differences between the number of errors made while reaching criterion for abstract sounds and icons (Day 3, $D=18$, $p<.05$; Day 8, $D=18$, $p<.05$) and abstract sounds and speech (Day 3, $D=22.5$, $p<.05$; Day 8, $D=21$, $p<.05$). However, there was no significant difference between the number of errors made in reaching criterion for speech and icons on either day.

DISCUSSION

The results presented here indicate that associations between auditory icons and events are learnt and retained far more readily than those between abstract sounds and events. They also show that associations involving icons are learnt and retained just as readily as those involving speech. As noted above, several authors have demonstrated the difficulty of learning and remembering large sets of abstract-sound warnings (3, 4, 5) and others have shown we have a huge capacity for remembering environmental sounds (9, 10). The current research replicates these findings and provides a *direct* comparison of the ease of learning and retention of sets of auditory warnings comprised of these sound types.

The fact that associations involving auditory icons were learnt and retained as readily as those involving speech indicates that the former have great potential for use as auditory warnings. Like abstract sounds, auditory icons can convey information rapidly and are less likely than speech warnings to be masked by background speech. Unlike abstract sounds, however, they are not obviously limited with respect to the set size that can be learnt. Much of the advantage that icons enjoy over abstract sounds is likely to derive from the ease with which the former can be assigned verbal labels. Bower and Holyoak (12) and Bartlett (11) have presented evidence that of the different types of representation that may be stored when a sound is committed to memory, verbal labels provide the most powerful basis for subsequent recognition.

Learning and retention of icon-event associations can presumably be enhanced by suitable pairings of icons and events. It is likely that a pairing that takes advantage of a strong, pre-existing relationship will result in greatly facilitated learning and retention. Some of the strongest pre-existing relationships should be between sounds and the events that cause them and, as noted by Gaver (8), icon-event pairings of this nature should be the easiest to learn. The one such pairing in this study was between the sound of a machine gun being fired and the event “anti-aircraft artillery”. It is interesting that this icon was one of only two that were identified correctly on all occasions. Unfortunately, events will sometimes need to be represented for which icons of this type are either not available or inappropriate for some reason. In these cases other pre-existing relationships could be tapped into, such as the “metaphorical” relationships referred to by Gaver (8). Whether icon-event pairings of this nature will result in significantly enhanced learning and retention is unclear and provides a worthwhile topic for future investigation.

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