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THE FEASIBILITY OF A LIGHT AND SOUND SYSTEM FOR DELAYING INTRUDERS INTO SECURE FACILITIES

By

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1.0 INTRODUCTION

To maximize the security of sensitive areas inside buildings, the U.S. Army is developing a highly secure Facility Intrusion Detection System (FIDS) that will eventually be installed in joint service DoD facilities. The FIDS will consist of a wide variety of sensors capable of detecting intruders, together with advanced components designed to provide a second line of defense against actions performed by intruders once they have been detected. One of these advanced components is a response/deterrent device that will be activated at the central monitoring location to deter intruders from accomplishing their mission, or delay them until guard forces arrive to investigate the intrusion.

The purpose of the study described in the present paper is to explore the feasibility of using light and sound stimuli as an intruder deterrent device by generating confusion, discomfiture, and disorientation, and hence impairing the intruder's efficiency at performing tasks, or deterring him from proceeding further with his mission. The advantage of such a system is that the light and sound stimuli can be generated with readily available equipment and, by careful design, can interfere with intruder behaviors in a manner that is clean, safe, and efficient. There is no residue to dispose of afterwards and no risk of permanent physiological damage in case of false activation or accidental exposure.

2.0 SELECTION OF POTENTIAL STIMULI

As a first step in developing a possible operational deterrent system, the scientific literature on the effects of sounds and lights on people was reviewed in order to select potential stimuli.

2.1 Sound Stimuli

The various categories of sound effects on humans, the elicited responses for each category, and their probable relevance to the present program are given in Table I. This table reflects the general range of sound effects,[1-4] and is also consistent with these effects identified by the Defense Nuclear Agency[5] as being relevant for intruder delay. Some of these effects have long-term rather than immediate implications, and others are unsafe or difficult to evoke with practical equipment. A review of the information in Table I indicates that there are three effect categories that potentially can be useful in delaying an intruder, and that are at the same time relatively safe, namely:

- Psychological
- Communication Disturbance
- Musculo-Skeletal

Table I

Sound Effects Considered for the Program

Effect Category	Nature of Effect	Applicability	Stimulus
Psychological	Annoyance Confusion Fear Arousal Distraction	Proven, Safe	Multiple Tones (3000 and 3005 Hz) generating beats Police Siren — "Yelp"
Communication Disturbance	Speech Interference	Proven, Safe	Broadband Noise
Musculo-Skeletal	Startle	Proven, Safe	Gunshot
Auditory System	Pain, Deafness	Proven, Unsafe	----
Non-Auditory Physiological	Nausea, Blood Pressure Changes, Gastro-intestinal Disorders	Not Proven, Potentially Unsafe	----

Psychological

The term "psychological" is used for effects which are functionally related to task performance, i.e., noise causes a specific response which may directly impair a human capability needed for the task – like vision, hearing, physiological homeostasis, muscle control, etc. Here "psychological" refers to responses like arousal, distraction, annoyance, confusion, and fear. Although these "psychological" effects can be elicited coincidentally by sounds which cause communication disturbance and musculo-skeletal response, they are often maximized by the presentation of multiple annoying tonal sounds varying in level and character. To produce such effects, the selected sound stimulus consisted of two pure tones at 3000 Hz and 3005 Hz, generating beats at the difference frequency of 5 Hz. The rationale for the use of these pure tones is that they cause a heightened annoyance compared to broadband noise at the same level, and that the annoyance is maximum at about 3000 Hz. The beats provide the sensation of a varying sound level and character which contributes further to uncertainty and annoyance.[6]

Communication Disturbance

There are basically three communication channels that may be interrupted:

- Between co-intruders (or intruder and outside accomplice),
- Between the intruder and the reaction forces, and
- Between the intruder and his task (subtle sounds used as cues).

Communication interference can be achieved by the use of masking noise which causes a communication "signal" (i.e., the sound which conveys the meaning one wishes to interfere with) to be rendered less intelligible or even inaudible. The level and spectrum of an effective masking noise can be determined from a knowledge of the level and spectrum of the signal. Thus a masking noise can be matched to a specific signal, or alternatively a broadband masking noise of sufficient level can mask a whole range of different signals.

The masking method described above can be applied to all three communication channels mentioned earlier. However, the addition of certain broadband masking noise, since it tends to be monotonous, can have a soothing effect contrary to the requirement to arouse, distract, and confuse (and also at variance with the needs of "startle" stimuli as described later). To overcome this limitation, the noise can be interrupted at irregular intervals.

Musculo-Skeletal

The startle response is a musculo-skeletal effect of noise that has both physical and psychological dimensions. Its physical nature includes involuntary muscle-flexures ranging from an eye blink to forward motion of the trunk.[7] The muscle-flexure in the startle response affects most tasks requiring precise motor coordination, but lasts only a few seconds. However, more complex tasks (e.g., those involving visual discrimination and concentration) can suffer performance degradation for up to one minute. The startle effect has been found previously to be involuntary and almost independent of an individual's skill in performing a task.[8]

Sound Stimuli Considered and Discarded

Infrasound was considered for the present program, but rejected because the equipment required for its generation is generally massive, especially where room volumes are high. Typical generating systems,[9] for example, involve powerful loudspeakers, jet engine exhausts, blowdown wind tunnels, large hydraulic pistons, or very large sirens. Combined with this difficulty in generation are the rather insubstantial effects noted after short-term exposures at all but very high levels of infrasound.[10]

Ultrasound was also considered for the present program and rejected on similar grounds to infrasound. Although its generation is fairly straightforward, sound at these high frequencies is highly directional, and requires special attention in transducer design and/or arrangement. The sound pressure levels at which ultrasound produces task effects are also extremely high: such effects as dizziness and loss of equilibrium are believed to require levels of 160 dB or so, well above those levels identified as the safe limit.[3]

Sound stimuli containing information (e.g., the noise of approaching security forces) were considered inappropriate to the circumstances under which the tests were to be conducted. All of the research participants would be aware that the tests were in no way really clandestine. Therefore such stimuli would have little meaning relative to task performance.

2.2 Light Stimuli

The various categories of light effects on humans, the elicited responses for each category, and their probable relevance to the present program are given in Table 2. A review of this information indicates that there are two categories that are both safe and potentially relevant, namely:

- Visual/Perceptual Disturbance,
- Postural Disturbance.

Visual/Perceptual Disturbances

A properly functioning visual system is a requisite to most tasks which an intruder may be required to perform. Therefore, if an intruder's normal visual functions are impaired or rendered useless, his task performance will likely be degraded. It is possible to impair visual functions by exposure to light stimuli of certain intensities and durations, the specific stimulus parameters being determined by the desired effect. The visual disturbances which can be safely elicited from visual stimulation are delayed dark/light adaptation and temporary flashblindness.

Dark adaptation is the process which the visual system undergoes when a person enters a dark area from a lighted area. Although the dynamic range of the visual system is large, the full range is never available as rapidly as in the auditory system. Since the adaptation time of the visual system to dark conditions is many times slower than it is to light conditions, it is possible, by flashing a light of sufficient intensity, at a sufficient rate, to render an intruder continually "blind" by never allowing his eyes to adapt fully to the dark conditions between flashes. However, the full adaptation time will be decreased in the presence of background illumination, such as that provided by an intruder's flashlight.

Table 2

Potential Effects of Light Stimuli

Effect Category	Nature of Effect	Applicability	Stimulus
Neurological	Epileptic Attacks	Proven, Unsafe	----
Visual Disturbances	Blindness	Proven, Unsafe	----
	Perceptual-- Impairs Vision	Proven, Safe	Flashing Lights
Postural Disturbances	Disorientation, Sway, Decreased Motor Control	Proven in Laboratory, Safe	Moving Light/ Dark Patterns

Flashblindness is an exaggerated form of dark adaptation, wherein a spatially distinct afterimage of the source is formed on the retina, provided that the source is of sufficiently high intensity. The time for the afterimage to disappear, the recovery time, increases as the background luminance decreases. Therefore flashblindness is a potential candidate for degrading task performance in low ambient light conditions.

Postural Disturbance and Disorientation

Posture disturbance and disorientation are obvious adverse influences on intruder task performance when their symptoms are sufficiently pronounced to constitute leaning, swaying and perhaps falling, as well as a general decrease in motor control. Posture disturbance can be achieved by light stimuli that provide the visual system with a false sensation of body position. This visually induced perception of motion, called vection, can be induced in the laboratory by means of rotating patterns of light.[11] Adaptation to the ambient light conditions can be minimized by periodically flashing the source.

3.0 EXPERIMENTAL PROGRAM

3.1 Introduction

The experimental program was designed to assess the effect of selected, physically safe levels of light and sound on human task performance. Its purpose was to develop a light and sound stimulus package that significantly degrades human performance. The light and sound system is intended to be used in secure areas to stop, delay, or dissuade intruders, without causing permanent physical harm.

The experimental program was divided into two phases:

- Stage One, Pilot Testing, was designed to:
  - a) assess the independent impact of the stimuli on task performance, using a small number of non-naive research participants;
  - b) assess the impact of combinations/sequences of stimuli on task performance, and select the optimum configuration;
  - c) pretest and refine stimulus-generating equipment, tasks, room configuration, data collection instruments, and experimental procedures.
- Stage Two, Primary Test Sequence, was designed to test the selected stimulus configuration using large numbers of naive participants performing tasks under control (with no stimuli) and experimental (with stimuli) conditions.

Before conducting the experimental program, a formal test plan was prepared and submitted to the Department of the Army, Surgeon General's Human Subjects Research Review Board (HSSRB), for review. It was approved by the Surgeon General prior to conducting the tests.

3.2 Testing Procedure

The experimental tests were conducted in a room measuring 18.5 feet by 40 feet with a height of 10 feet. For all trials, the room was darkened and the participants were equipped with a 2D-cell flashlight.

Two research participant populations were used during the present program. Naive participants, males, 18 to 25 years of age, were utilized throughout all stages of work, performing just one task under one experimental condition. Non-naive participants, Wyle personnel, including project research staff, were utilized repeatedly only during Stage One, Pilot Testing under a variety of experimental and control conditions for stimulus screening purposes.

The research participants were questioned concerning health, vision, and hearing problems. Participants who did not meet the safety criteria established for the proejct were excluded from participation. Qualified participants filled out informed consent forms and were then assigned to one of two groups: one group initially performing a task under control (no stimuli) conditions, followed by a test run with a different task under experimental stimuli conditions; and an experimental-only group, performing one experimental condition run with no exposure to control conditions.

Throughout the testing program, safety was assured by excluding research participants with medical problems identified from medical histories, by performing pre- and post-test audiometric tests, and by providing safe conditions and safety devices in the test room. To ensure that safe conditions existed within the test room, none of the light and sound stimuli included frequencies or intensities with the potential to cause permanent physical effects or EEG photic driving (seizures). The A-weighted sound levels were set at 110 dB for continuous sound stimuli, while impulsive sound levels (bangs) did not exceed 120 dB. Furthermore, impulsive sound was not mixed with continuous sound, but was preceded by a brief period of silence that was continued through the presentation of each bang.

Finally, physical devices were located in the test room to provide for participant safety. These devices included a vision port to ensure that participants were under constant observation and could have been removed had a difficulty developed. The control panel contained a single switch to turn off all sound to the test room. Each participant was provided with a radio transmitter attached to his belt that could be actuated by pressing a button if he were in any form of distress. Finally, a local physician was informed about the test program and made available to respond if any health problems arose.

As a result of these safety precautions, no health problems arose in the testing program. No research participants were injured, and none experienced visual or auditory after-effects that extended more than a few hours after exposure.

3.3 Performance Tasks

Five performance tasks were created to replicate portions of likely intruder behavior. They can be broadly grouped into two categories:

a) tasks emphasizing cognitive functioning, and
b) tasks emphasizing physical performance.

The tasks emphasizing cognitive functioning were Document Sort and Control Panel tasks. The tasks emphasizing physical performance were the Crawford Small Parts Dexterity Test, Voice Communication, and Gross Motor Coordination.

- Crawford Small Parts Dexterity Test – selected to address those portions of an intruder's behavior requiring fine motor control and close eye-hand coordination. The task consists of two parts: screwing screws into threaded holes using a screwdriver, and the placement of pins in holes and metallic collars over the pins using a tweezer.

- Voice Communication – simulating the situation where two or more intruders enter a secure facility, and need to coordinate their actions by voice communication.

- Document Sort – simulating the behavior of an intruder looking for specific documents in a file cabinet, addressing reading skills and cognitive functioning in the form of the development of search patterns and decision making.

- Control Panel Task – designed to simulate those portions of intruder behavior where the intruder must remember a set of instructions or a numerical sequence (e.g., a safe combination) and is required to use that information in the secure facility. This task focused on memory and arithmetic cognitive functioning.

- Gross Motor Coordination – designed to simulate the intruder situation where two or more intruders enter a secure facility and remove a quantity of objects.

4.0 TEST RESULTS AND CONCLUSIONS

4.1 Definition of Final Stimuli Characteristics

Throughout the pilot test phase, three issues were of primary importance in developing the final stimulus configurations: the effectiveness of each stimulus in degrading task performance, the compatibility of each stimulus with the others, and safety. The research effort was oriented toward developing a stimulus package that not only was effective, but also functioned as an integrated unit with individual stimulus components well matched to each other.

As a result of the pilot test phase, four sound stimuli were selected, together with two types of light stimuli, to produce the final stimulus configuration. The four selected sound stimuli were:

- Broadband white noise, filtered to eliminate frequencies below 100 Hz and above 2900 Hz, at a sound pressure level of 105 dBA;
- A commercial electronic police siren, set on the "Yelp" mode, at a sound pressure level of 105 dBA;
- Two pure tones, one tone fixed at 3000 Hz, the second tone fixed at 3005 Hz, at a sound pressure level of 105 dBA;
- Impulsive noise, "bangs", at a peak sound pressure level of 120 dB.

The two light stimuli were:

- A repeating strobe unit, 50 joules per flash, operating at one flash per second, directed at the task work surface;
- Six standard photoflash units placed on the test room walls, operating at a variable rate in the range of one flash every one to two seconds.

Two variations of rotating patterns of flickering light intended to produce posture disturbance were tested and discarded. Previous experiments have successfully utilized rotating patterns of flickering lights, under laboratory conditions, to produce a vection effect. Two types of mechanical devices producing rotating, oscillating, and flickering lights, with several different light patterns, were assembled and tested in the pilot test phase. In neither instance was a significant vection effect evident. It was concluded that the presence of non-moving objects in the room provided a fixed frame of reference, thus eliminating the vection effect.

4.2 Test Results

Method of Analysis

For each of the five tasks, two effects of the stimuli were analyzed separately: the time that participants required to complete the task, and the number of errors that they made. For each task, differences in time and error counts between experimental and control groups were determined by using t-Tests.

Two variations of experimental conditions were utilized – participants either first performed a control condition task before performing a different experimental condition task, or they just performed an experimental task without any control task experience. Thus three t-Test comparisons were made: control condition/subsequent experimental condition, control condition/experimental-only condition, and control condition/both subsequent experimental and experimental-only conditions combined. Separate analyses were indicated because the participant's experience in the test room under control conditions might have reduced his apprehension under subsequent experimental conditions. Very little difference was found, in terms of statistical significance, direction, or magnitude of effects between the three differing forms of analysis. Therefore, for brevity, the table that follows reflects only those comparisons utilizing the full data set (control/both subsequent experimental and experimental-only conditions).

Where statistical analysis demonstrates that the experimental stimuli have degraded the participants' time performances, the delay factor of the stimuli is presented. The delay factor is defined as the ratio of the time to perform the task under experimental conditions to the performance time under control conditions. The delay factor is thus the fractional change in performance time produced by the stimuli.

The distribution of research participants by task and test group is displayed in Table 3. The total participant sample available for comparison was 195. However, because of problems with some participants' understanding of the directions for the task to which they were assigned, as well as coding and transcription errors, only 177 cases were used for the analyses.

The test results are summarized in Table 4, showing performance degradation in terms of the delay factor, in terms of errors, and the statistical significance of both these quantities.

Performance Degradation – Time

Participants performing three of the intruder-like tasks, under experimental conditions, clearly demonstrated that the stimuli have a significant delay factor. The performance times are summarized in Table 4. It took substantially longer for participants to complete the Crawford Small Parts Dexterity Test, Voice Communication,

Table 3

Distribution of Subjects by Task And Test Group

TEST GROUP	TASK					
	Crawford Small Parts Dexterity Test	Voice Communication	Document Sort	Control Panel	Gross Motor Coordination	Total
Control Condition	17	1	10	20	26	74
Experimental Condition	13	1	14	14	27	69
Experiment Only Condition	6	9	9	3	7	34
Total	36	11	33	37	60	177

Table 4

Summary of Test Results

TASK	TIME		ERRORS	
	Statistical Significance*	Delay Factor	Statistical Significance	Performance Degradation
Crawford Small Parts Dexterity Test	YES	1.42	MARGINAL	375%
Voice Communication	N/A	$\geq$2.00	N/A	570%
Document Sort	YES	1.26	NO	NO
Control Panel	YES	<1.00	NO	MARGINAL
Gross Motor Coordination	YES	<1.00	NO	NO

* Using 95 percent confidence level as the criterion for significance.

and the Document Sort tasks in the presence of the light and sound stimuli than under the control conditions. The magnitude of this effect ranged from an inability to complete the task (Voice Communication) in the time allotted, to a delay factor in the range of 1.26 to 1.42 (Crawford Small Parts and Document Sort).

The research participants did not demonstrate a performance time degradation when performing two tasks, Control Panel and the Gross Motor Coordination, but completed these two tasks in less time under experimental conditions than under control conditions. These tasks have one common element that may provide an explanation: they both involve substantial amounts of walking within the test room. It was observed that the participants, under control conditions, walked rapidly from location to location in the test room. However, under experimental conditions, they were observed to run from location to location. Clearly, the light and sound stimuli used, at the intensities and frequencies permitted (consistent with participant health and safety), did not interfere with the participants' walking ability. At the same time, the uncomfortable nature of the stimuli motivated them to move quickly, so as to leave the test room as soon as possible. It is possible that exposure to higher levels would encourage even more rapid movements resulting in an increase in errors.

Performance Degradation — Errors

The stimuli showed a significant performance degrading effect in terms of error rates for two of the five tasks: Crawford Small Parts Dexterity Test and Voice Communication. The percentage change for the Crawford Small Parts Dexterity Test is 375 percent, indicating that participants, under experimental conditions, had increased difficulty controlling fine motor functions and eye-hand coordination. The increase in error rate from 1 to 50 percent for Voice Communication is consistent with the observation that the stimuli almost totally disrupted the ability to communicate verbally. Three tasks, Document Sort, Control Panel, and Gross Motor Coordination, demonstrated no performance degradation in terms of error scores.

The Document Sort and Control Panel tasks emphasized cognitive functioning. The data indicate that the stimuli, at the intensities and frequencies permitted, did not disrupt the types of cognitive performance required for these tasks. One caveat is important here, however. Participants performing the Document Sort required a longer time period to complete the task. While they did not demonstrate a concomitant increase in errors, it may be that the participants traded time for accuracy. That is, the participants took a longer time in order to ensure that they performed accurately. Finally, the Gross Motor Coordination task demonstrated no increase in error rate.

4.3 Conclusions

The data indicate that the stimuli have a significant delay factor for certain types of intruder tasks. They have a substantial impact on eye-hand coordination, fine motor control, and the ability to rapidly read, search, and make decisions associated with finding target documents in a filing system. In addition, they almost totally disrupt voice communication. However, the particular stimuli chosen do not affect the ability to walk.

Given that the light and sound stimuli were conservatively safe for human exposure, and that the test conditions could not duplicate the apprehension associated with a real intruder situation, the results appear to be quite encouraging. It is not possible to extrapolate these data to predict the delay factor at higher exposure levels. However, it is reasonable to assume that the effectiveness of the stimuli at degrading task performance should increase – perhaps substantially – with increasing levels.

Further research is presently being conducted to investigate the effects of somewhat more intense stimuli for potential inclusion in a hardware system. The significant behavioral effects already achieved on oral communication, eye-hand coordination, and searching efficiency, all essential elements in the highly uncertain environment of the intruder, offer promise of developing a security system that serves as a clean, safe, and efficient retardant.

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