HUMAN FACTORS, 1991, 33(4), 389–400

Aurally Aided Visual Search in the Central Visual Field: Effects of Visual Load and Visual Enhancement of the Target

DAVID R. PERROTT,[1] TOKTAM SADRALODABAI, *and* KOUROSH SABERI, *California State University, Los Angeles, California, and* THOMAS Z. STRYBEL, *California State University, Long Beach, California*

Visual search performance was examined in a two-alternative, forced-choice paradigm. The task involved locating and identifying which of two visual targets was present on a trial. The location of the targets varied relative to the subject's initial fixation point from 0 to 14.8 deg. The visual targets were either presented concurrently with a sound located at the same position as the visual target or were presented in silence. Both the number of distractor visual figures (0–63) present in the field during the search (Experiments 1 and 2) and the distinctness of the visual target relative to the distractors (Experiment 2) were considered. Under all conditions, visual search latencies were reduced when spatially correlated sounds were present. Aurally guided search was particularly enhanced when the visual target was located in the peripheral regions of the central visual field and when a larger number of distractor images (63) were present. Similar results were obtained under conditions in which the target was visually enhanced. These results indicate that spatially correlated sounds may have considerable utility in high-information environments (e.g., piloting an aircraft).

INTRODUCTION

In the cockpit of the future, it is anticipated that discrete displays will be replaced with systems that generate three-dimensional presentations of the flight environment. Although such virtual environments will probably have the capacity to provide information to the pilot through several sensory channels, it is reasonable to expect that the bulk of the information will continue to be directed to the visual modality. It is assumed that such systems will improve flight performance by providing the pilot with information that can be sensed directly, rather than inferred from a number of discrete displays distributed in the cockpit (Thompson, 1987).

One advantage of a virtual environment is that it can simulate an unrestricted view of the surrounding space. Such a system must, however, still work within the natural constraints imposed by the pilot's capacity to utilize visual input. As noted by Gibson (1950), humans view the world through a window extending, relative to the current line of gaze, no more than 80 deg laterally and 60 deg vertically. But even within this

[1] Request for reprints should be sent to David R. Perrott, Psychoacoustics Laboratory, California State University, Los Angeles, CA 90032.

window spatial information-processing capacity is not uniform. For example, only for a relatively narrow segment near the center of this field (immediately around the line of gaze) do we find good spatial acuity. For the peripheral portions of this field—approximately half of the available window—spatial resolution is generally less than 5% of that obtained at the fovea (Wertheim, 1894). Thus even though a virtual environment may extend the availability of visual information, the pilot can sample only a limited portion of the field at any moment. In effect the pilot's central visual field is a critical resource that must be used effectively if the full potential of the virtual environment is to be realized.

One approach to this problem of resource allocation has been to provide simulated three-dimensional auditory displays via headphones. As noted by Doll, Gerth, Engelman, and Folds (1986), such a system, when combined with a head-coupled system (a system that tracks the current position of the pilot's head), could improve situational awareness by informing the pilot that critical visual information outside of the current visual field is available. By extension, it is even possible that this auditory signal might indicate exactly where the information is located relative to the current position of the pilot's head. The current investigation is part of a program of research concerned with this latter issue which is being conducted in our laboratories. Can spatial information from the auditory channel be employed in the redirection of gaze?

Aurally Aided Visual Search Performance

We have examined visual search performance as a function of the availability of spatial information from the auditory modality (Perrott, Saberi, Brown, and Strybel, 1990). The time required to locate and identify a visual target was measured under conditions of high spatial uncertainty; the horizontal location of the visual target was varied within an area of 260 deg, centered at the midline of the subject's head. Two conditions were examined. In the first condition an auditory signal (10 Hz click train) located in front of the subject was used to indicate that a visual target was present. In effect, the sound provided information regarding the status of the field (supporting the subject's situational awareness), but it provided no information regarding the location of the target to be identified. In the second condition the location of the auditory signal was identical to the location of the visual target. In this case both target location and situational information were available to the subject. In both conditions the auditory signal was superfluous to the discrimination task itself because it provided no information regarding the identity of the visual event (one of two letters was employed on each trial).

When the location of the auditory signal was identical to the location of the visual target (the spatially correlated condition), visual search time was reduced at all target locations relative to that obtained in the absence of this spatial information from the auditory modality (the spatially uncorrelated condition). The magnitude of the advantage observed when the search was aurally aided depended on the relative location of the target. For extreme peripheral locations outside the visual field (at least 80 deg from the initial line of gaze), search time was reduced by 500 to 700 ms when the auditory spatial information was available. For target locations between 10 and 80 deg, the peripheral visual field, a reduction of 200 to 500 ms in the latency was obtained. Finally, even when the visual target was located within 10 deg of the initial line of gaze, the central visual field aurally aided visual search was 175 ms faster than that obtained without spatially correlated information from the auditory channel. This last finding was most surprising. Simi lar results were also obtained when the visual target was free to vary in the vertical dimension as well.

These improvements in visual search time were obtained when a single target was presented to the subject. In aerospace applications a pilot could frequently be faced with multiple potential targets present in the visual field at the same time. The present investigation considered the effects of auditory spatial information on visual search performance over a range of visual loads. Furthermore, the location of the visual target was restricted to a region within 15 deg of the subject's initial line of gaze. Two reasons for this latter constraint were considered. First, we were interested in attempting a systematic replication of the most surprising observation from our previous research on this problem—the finding that even for events within the central visual field, the presence of spatial information from the auditory channel can improve the efficiency of the process by which a subject can realign gaze so as to bring a visual target into registration with the fovea. Second, it seemed reasonable to expect that the central visual field would be the preferred site for the presentation of critical information. Two experiments were completed to measure the effect of a spatially correlated acoustic stimulus on visual search time under conditions of varying visual load within 15 deg of the subject's initial line of gaze. The first experiment examined performance obtained with 0 to 63 distractor stimuli in the field during the search interval. The second experiment considered the effects of aural aids on visual search with visually enhanced targets.

EXPERIMENT 1

Method

Subjects. Eight university students 23 to 38 years of age served in this experiment. All subjects employed had normal or corrected-to-normal vision with no known hearing deficit.

Materials and apparatus. The experiment was conducted in a large test chamber (12.2 × 9.1 × 3.7 m) that had been modified for free-field listening. All interior surfaces were covered with 10.2-cm acoustic foam wedges (Sonex, NXS-4), which have an absorption coefficient of 0.99 for frequencies about 700 Hz. The acoustic characteristics of the test chamber were excellent for the 800 to 9000-Hz bandwidth signals employed in the current experiment.

A microprocessor and digital interface (of local construction) were used to generate and distribute the audio signals used in this experiment. Square wave pulses (0.15 ms) were led to one of 21 speakers (Quam) located in the experimental chamber. The output of the speakers, as measured at the location occupied by the subject during testing, was a 47-dB (A-weighted) transient of approximately 1.6 ms duration. The contributions of the midrange speakers to the acoustic stimuli available were substantial. In addition to the tenfold increase in signal duration obtained (the 0.15-ms square wave electrical impulse, which was delivered to the speaker, resulted in a 1.5-ms acoustic event), the acoustic transient was limited to frequencies between 800 and 9000 Hz. In effect, the signal bandwidth was limited by the transducers employed.

Given the low frequency of the click train employed (10 Hz) and the resulting long interclick interval (nearly 100 ms), relatively little temporal summation would be anticipated. Under these conditions it seemed reasonable to measure signal level by presenting individual transients and obtaining the peak response of the sound-level meter (capture and hold). The speakers were mounted directly behind a 1.7 × 1.1 m cotton screen (of local construction), on which the visual stimuli were projected. The screen was essentially transparent to the acoustic signals we employed.

The visual stimuli were also computer generated. The target figure was a pair of lines forming a right-angle corner with both lines orientated on the oblique. Two orientations were employed: pointing left (<) and pointing right (>). Distractor stimuli were identical to the target figure except that the two component lines were orientated toward the horizontal and vertical axes, respectively. The graphic figures were projected onto the cotton screen in the test chamber (In Focus System model 7199). Luminance measures indicated a level of 4.086 cd/m^2 for the background and 9.340 cd/m^2 for the figures (a contrast of 0.391). The targets subtended a visual angle of 0.97 deg when viewed from a distance of 3 m. Distractor stimuli varied in size from 0.48 to 0.97 deg.

Both the auditory and visual stimuli were presented at suprathreshold levels. No subject reported having any difficulty in detecting and identifying the relatively large visual targets employed in this experiment or in hearing and localizing the 10-Hz click train. Short of a substantial hearing loss, there is little evidence that any close relationship exists between performance on an audiogram, for example, and auditory localization function.

For aspects of this experiment in which exact timing was critical, machine language subroutines were employed. Reaction time measures, for example, were obtained with 1-ms accuracy by using the hardware clocks available on the microprocessor (Hormann and Allen, 1987), and the initiation of the visual targets was synchronized with the computer-generated raster sweep.

Procedure. A two-alternative, forced-choice discrimination task was employed. Subjects were instructed that one of two targets would be presented on the screen located 3 m in front of them. They were to press the right key of a two-key panel if the visual target was an arrowhead facing right (>) and the left key if the arrowhead was facing left (<). Prior to the presentation they were required to fixate on a cross (subtending a visual angle of 1.0 deg), which was projected onto the center of the 1.7 × 1.1 m screen. The fixation figure was presented for a variable period (between 1.5 and 2.0 s). Upon termination of this figure, the reaction time clock was started and the target and distractor figures were projected onto the screen. Subjects were instructed to locate and identify the target as quickly as possible.

With the offset of the fixation figure, the target was projected onto one of 21 locations relative to the center of the fixation figure. One of the target locations (0 deg displacement), was the same position as the fixation cross. For the remaining 20 locations, four positions were selected at each of the following distances from the fixation point: 2.4 deg, 4.5 deg, 7.3 deg, 9.6 deg, and 14.8 deg. For target locations at a given distance from the fixation point (e.g., 4.5 deg), the visual field had been divided into four regions relative to the fixation point: above and to the right, above and to the left, below and to the right, and below and to the left. Thus for each distance, the target could be projected onto any one of the four quadrants. The actual position at a given distance and for a particular quadrant was assigned so as to avoid any obvious pattern of placement. Within a session all displacements from the fixation point (0–14.8 deg) were equally likely to occur on a given trial, with the constraint that 70 presentations were obtained at each distance. The location of the target, at a given distance from the fixation point, was randomized.

Concurrent with the presentation of the visual target, distractor stimuli were also presented. The numbers of irrelevant figures that could occur on a given trial were as follows: 0, 1, 3, 7, 15, 31, and 63. The location of a distractor stimulus was randomized with the following constraints: (1) the figure had to fall within 15 deg of the fixation point, (2) the figure could not occupy the same location as the target on that trial, and (3) no two distractor figures could occupy the same location on the same trial. Selection of the locations of the distractor figures was completed prior to each trial. Figure 1 illustrates a trial in which the target was located in the upper-right quadrant (labeled "Target" in this illustration) and 15 distractor figures were presented. The target figure in this example is pointing to the right. (Note that the fixation point indicated in the illustration was not present during the actual presentation and that the illustration is not to scale.) Within a session, all combinations of the number of distractors and displacements of the target from the fixation point were presented equally often (10 replications). The mean reaction time for each of the 42 conditions examined was obtained within a single session.

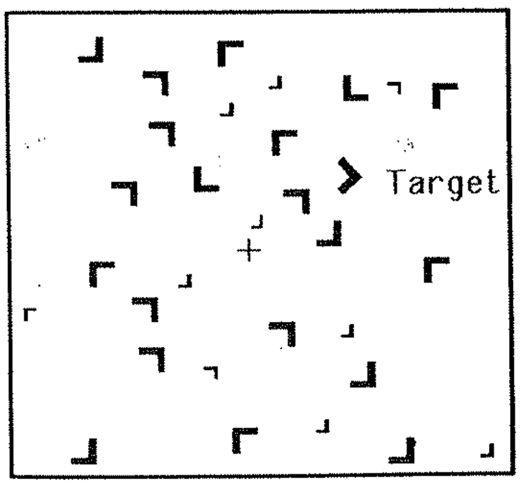

Figure 1. *Illustration of the array employed in the visual search task. The target, a greater-than symbol (pointing to the right), is located in the upper right corner of the field. The initial fixation point (the cross), centered in the field, was terminated at the onset of the target and distractor stimuli. In the current illustration there are 30 nontarget elements, which vary in both size and orientation relative to the target.*

Experimental conditions. Two conditions were examined. In the first, the offset of the fixation cross was the only signal used to cue subjects that the target had been projected onto the field. This condition was labeled the *no-sound condition.* In the second condition, with the onset of the target figure, a 10-Hz click train was available from a speaker located directly behind the screen and at the same position as that occupied by the visual target. We identified this as the *spatially correlated sound condition.* In every other aspect these two experimental conditions were identical.

Each subject completed four sessions (approximately 45 min/session) in each of the experimental conditions. The first session in each condition was defined as practice, and the data from that session were not included in the final data analysis. All subjects completed one of the two conditions prior to testing on the other. Although we had intended to fully counterbalance the order of testing, five of the eight subjects completed the spatially correlated sound condition first.

Several additional features of the conditions of testing should be noted. First, subjects received feedback on each trial about whether or not their response was correct. In fact, a 6-s time-out period was initiated after every incorrect response. This punishment was quite effective in reducing error rates. Second, the sessions were self-paced; that is, subjects could control the presentation rate by not responding. Long reaction times (in excess of 5 s) were recognized by the system as a subject-initiated time-out. These delayed responses were not included in the data summary at the end of the session. Third, the subjects were not informed of the number of possible target locations that might occur during a session. Because the presentation by quadrant was randomized, some target locations could occur relatively infrequently during a particular session. Finally, when questioned after completing the experimental sequence, subjects typically overestimated the number of possible target locations. In effect, we believe that our subjects experienced a high degree of uncertainty regarding the probable location of the next target from trial to trial.

Results and Discussion

Figure 2a presents the performance obtained in the spatially correlated sound condition, and Figure 2b presents the results from the no-sound condition. Each point represents the mean reaction time obtained across 240 trials. An analysis of variance performed on these data indicates that the number of distractors, $F(6,42) = 48.39$, $p < 0.01$, distance of the target from the fixation point, $F(5,35) = 68.68$, $p < 0.01$, and the presence or absence of a spatially correlated sound source, $F(1,7) = 18.13$, $p < 0.01$, are all significant factors determining visual search latency. The time required to locate and identify the visual target increases as the number of distractor stimuli increases and as the target is located farther from the initial fixation point.

The improvement in search performance obtained here when spatially correlated sound is present replicates the effects noted earlier in our laboratory (e.g., Perrott et al., 1990). What is particularly apparent from these figures is that an interaction exists between the number of stimuli in the field and the relative distance from the fixation point, $F(30,210) = 23.06$, $p < 0.01$. Not surprisingly, there is only a modest effect of the number of distractors in the field when the target was located at the same place as the fixation point, and there is a large effect for targets located more remotely from the fixation point. A two-way interaction also exists between the presence or absence of a spatially correlated sound and the distance of the target from the fixation point, $F(5,35) = 19.42$, $p < 0.01$. The presence of spatial information from the auditory channel attenuates the effect of target locus on visual search latency.

The presence of a three-way interaction, $F(30,210) = 17.90$, $p < 0.01$, between number, distance, and conditions is also evident in these figures. Two specific situations were isolated to better illustrate this effect. In the first of these (Figure 3), mean reaction time is plotted as a function of the number of stimuli in the field (1–64) when the target was located at the initial fixation point. An analysis of variance performed on this 0-deg condition indicated significant effects of condition, $F(1,7) = 6.69$, $p < 0.05$, and number of stimuli, $F(6,42) = 10.75$, $p < 0.01$. It is interesting to note that the number of stimuli in the field is a potent factor even when the target occurs at the initial fixation point (the latencies increase by 50–60 ms). Reaction times are faster by about 25 ms when spatially correlated sounds are available, regardless of the number of distractors present. This small but consistent advantage suggests that the auditory signal is simply a better stimulus to alert the subject that the target has appeared. Certainly no search would be required. Finally, there is no evidence of an interaction between conditions and the number of stimuli in the field when shifts in gaze are not required.

The presence of auditory spatial information can have a substantial effect on visual search for events more remote, as illustrated in Figure 4 (note the change in scale between Figures 3 and 4). The time required to locate and identify which of two targets was presented when the target was located 14.8 deg from the initial fixation point increased from

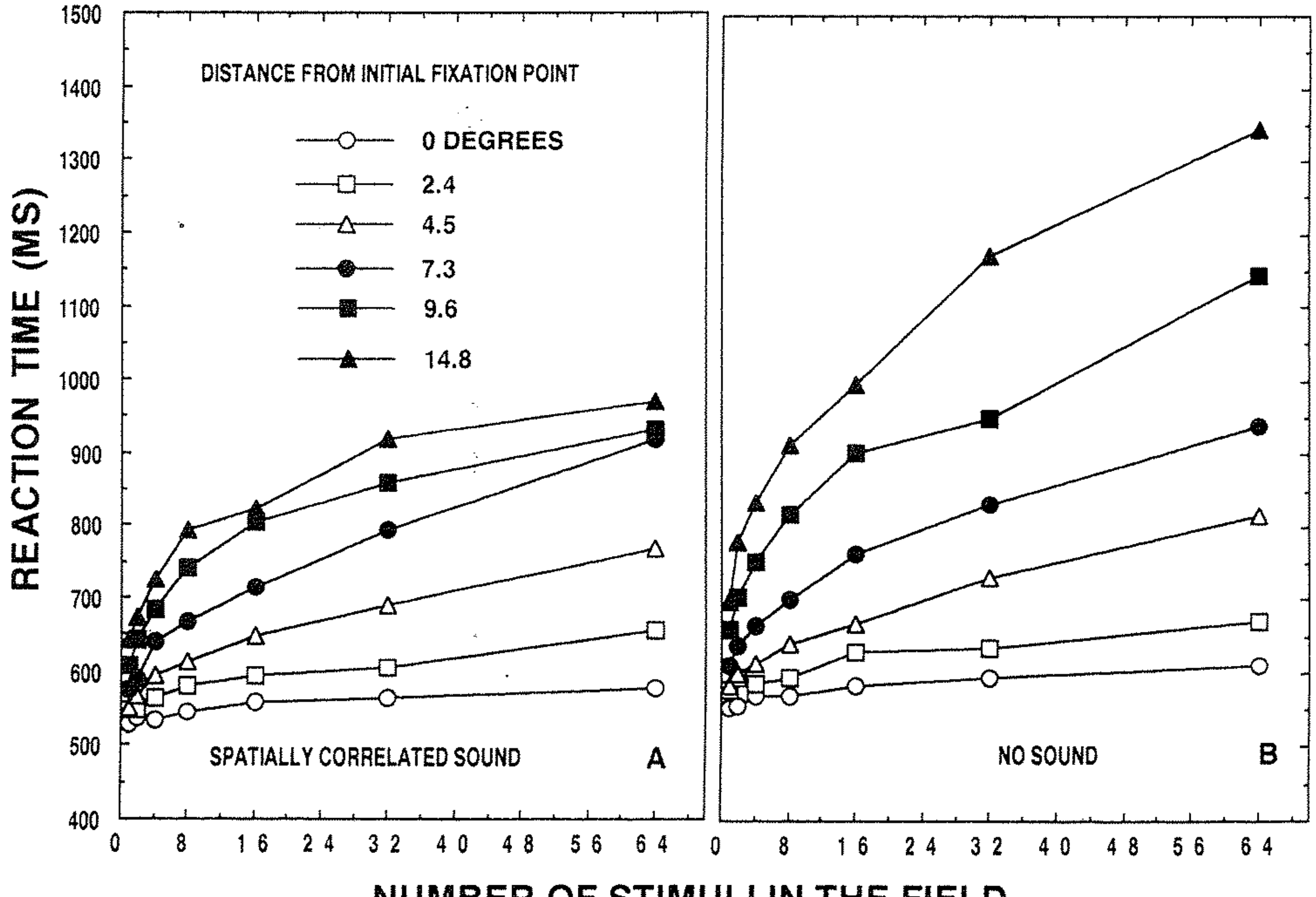

Figure 2. *Mean reaction time as a function of the number of stimuli in the field and the position of the visual target relative to the initial fixation point. Panel A presents the results obtained when a spatially correlated sound was present and Panel B when no sound was available. Each point represents the mean of 240 trials.*

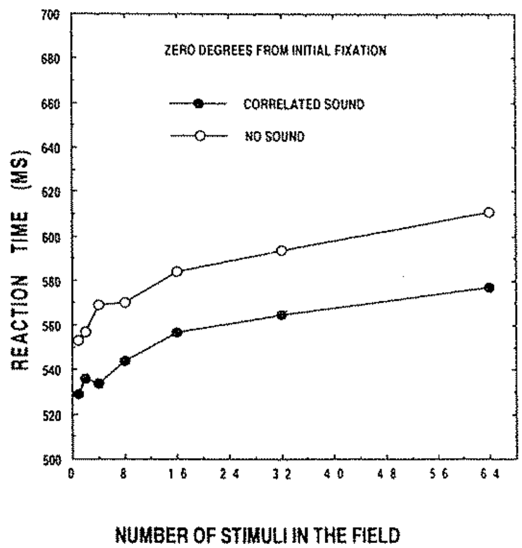

Figure 3. *Mean reaction time observed when the visual target was located at the fixation point. No shift in gaze was required to identify which target was present.*

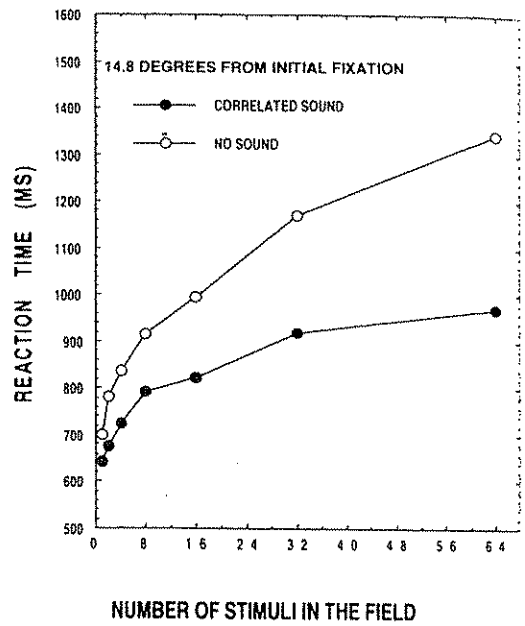

Figure 4. *Mean reaction time observed when the visual target was located 14.8 deg from the fixation point. A shift in gaze was required to identify which target was present.*

an average of 699 ms to 1343 ms as the number of stimuli increased from 1 to 64 in the absence of a spatially correlated sound (a 92% increase in the search interval). In the spatially correlated sound condition, 642 ms were required to locate and identify the target when only the target was present (a savings of only 57 ms relative to the no-sound condition). However, performance when a large number of distractor events were present indicates an advantage to the spatially correlated sound condition relative to the no-sound condition of 372 ms. In effect, an interaction between the number of stimuli in the field and the conditions of testing is evident in this figure, $F(6,42) = 6.39, p < 0.01$.

There is no evidence of a speed/accuracy trade-off by which one might account for the effects obtained in this study. The 0.9% mean error rate in the spatially correlated sound condition was essentially identical to that obtained in the no-sound condition (0.8%). An analysis of variance indicates that no statistically significant differences were observed in error rates as a function of the conditions of testing, $F(1,7) = 2.575, p > 0.05$).

The presence of spatial information from the auditory channel clearly improves visual search performance within what we have defined as the central visual field. Whereas the presence of auditory spatial information can reduce the latency to respond to a target located at the initial fixation point, even when no other visual stimuli are present, the utility of this information is particularly evident as the field becomes cluttered with additional visual images. Similarly, performance is more greatly affected when shifts in gaze are likely to be involved. The maximum benefits of auditory spatial information are evident when large numbers of events are present in the field and the target is more remote.

The utilization of auditory spatial information to direct the pilot's attention to particular events within the central visual field may not be cost-effective. Such a system requires both the ability to simulate a three-dimensional sound field and the capacity to appreciate the current location of the pilot's head. The same benefits might be more readily (and inexpensively) achieved—at least for targets in the central visual field—simply by utilizing the visual display so as to cue the pilot to where critical information can be found. In the following experiment the location of the target was visually cued. This performance was then compared with that obtained when spatial information from the auditory channel was also provided.

EXPERIMENT 2

Method

Subjects. Five university students 22 to 38 years of age served in this experiment. Two of the five had served in the earlier experiment. All subjects had normal or corrected-to-normal vision and no known hearing impairment.

Apparatus and procedure. The same apparatus and procedures as those described in Experiment 1 were employed, with the following change. The visual target was highlighted using a figure-ground reversal of the character cell containing the target (< or >). As described earlier, the background was dark (4.086 cd/m^2) relative to the figures (9.340 cd/m^2). In this experiment the background immediately surrounding the target was 9.340 cd/m^2, and the target was presented as a dark figure (4.086 cd/m^2) against this local white background. Distractor stimuli were still presented as light figures against an extended dark background. Again, tests were conducted in the presence and absence of spatially correlated sound information.

Results and Discussion

Figure 5a summarizes the performance obtained when the visual target was highlighted and spatial information from the auditory modality was provided. Figure 5b presents the results obtained in the absence of the spatially correlated sound. Each point plotted in these figures is based on the mean of 150 trials. An analysis of variance performed on these data indicates significance with respect to the number of stimuli in the field, $F(6,24) = 34.52$, $p < 0.01$, and the distance of the target from the initial fixation point, $F(5,20) = 63.45$, $p < 0.01$. The main effect for conditions of testing (sound vs. no sound) is not significant, $F(1,4) = 1.52$, $p > 0.05$. All of the two-way interactions are significant: Distance × Number of Distractors, $F(30,120) = 11.41$, $p < 0.01$; Conditions of Testing × Distance, $F(5,20) = 2.88$, $p < 0.05$; and Conditions of Testing × Number of Distractors, $F(6,24) = 8.13$, $p < 0.01$. The three-way interaction among conditions, number, and distance is again significant, $F(30,120) = 2.48$, $p < 0.01$.

As was evident in the first experiment, the impact of the spatially correlated sound information was slight when the target was located near the initial fixation point and few distractor stimuli were present. By way of example, Figure 6 presents the results obtained when the target was located only 2.4 deg from the fixation point. The open squares indicate the performance obtained under the condition in which the target was highlighted and a spatially correlated sound was present. The open circles indicate the latencies obtained with visually enhanced targets in the absence of a spatially correlated sound. The effects are small (approximately 10–25 ms) and are relatively independent of the number of distractor stimuli present. These results parallel those obtained in the first experiment, in which the targets are visually similar to the distractor images.

As noted in Experiment 1, the utility of the spatial information from the auditory channel is more evident for targets located farther

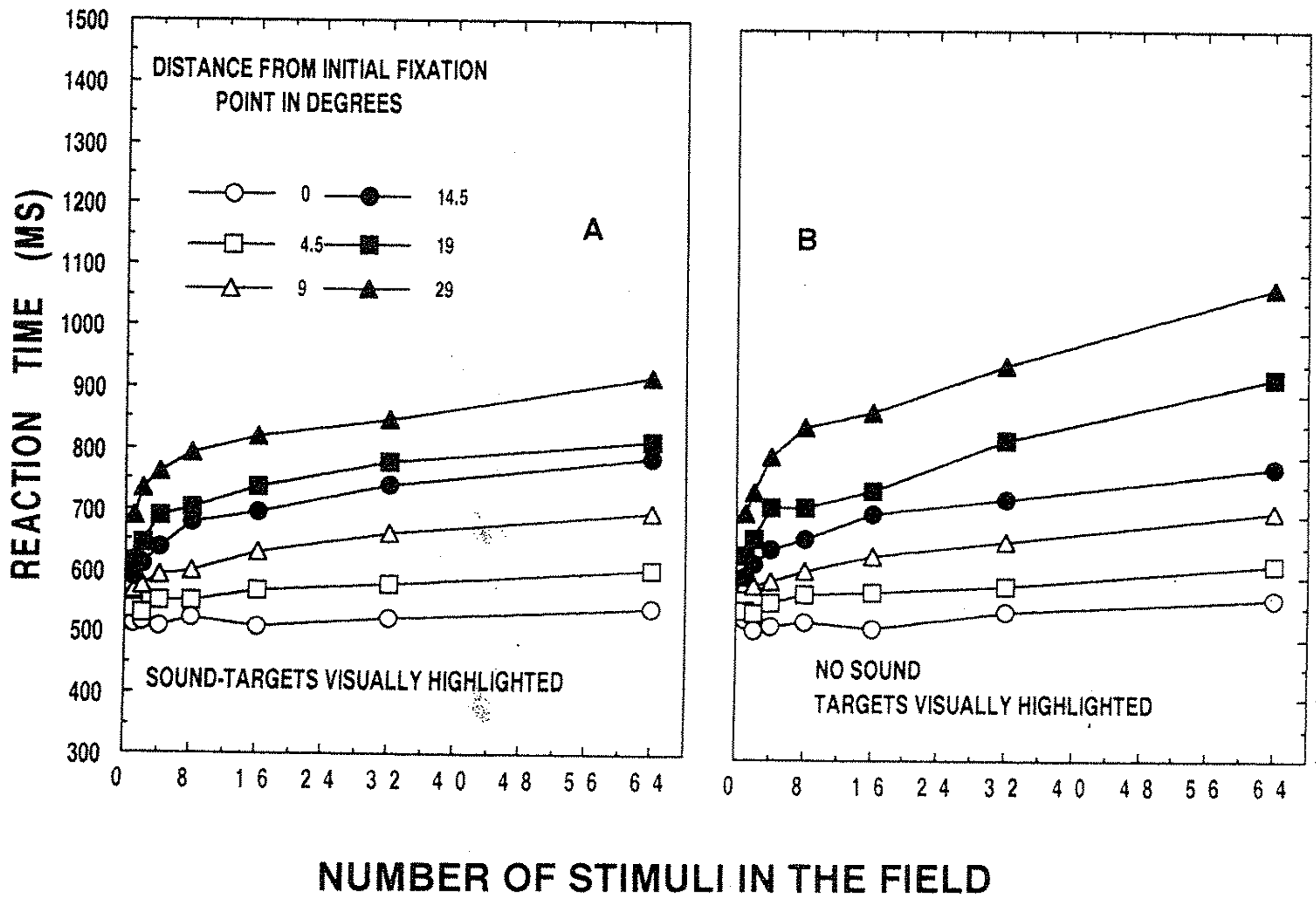

Figure 5. *Mean reaction time as a function of the number of stimuli in the field and the position of the visual target relative to the initial fixation point. Note that these results were obtained with enhanced visual targets. Panel A presents the results obtained when a spatially correlated sound was present and Panel B when no sound was available. Each point represents the mean of 150 trials.*

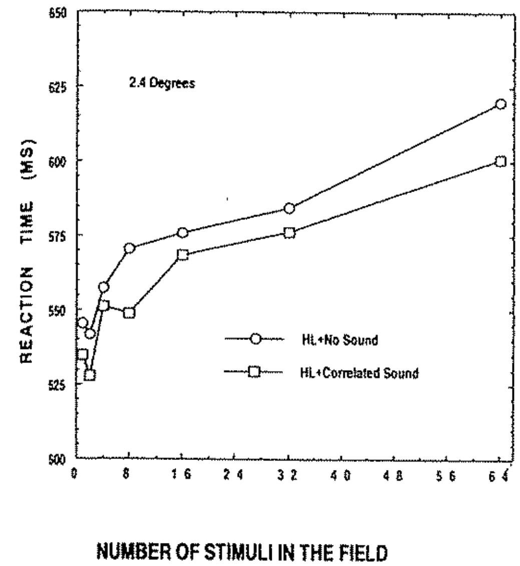

Figure 6. *Mean reaction time observed when the enhanced visual target was located near the fixation point (2.4 deg). Probably no shift in gaze was required to identify which target was present, given that the target extended 1.0 deg. HL = highlight.*

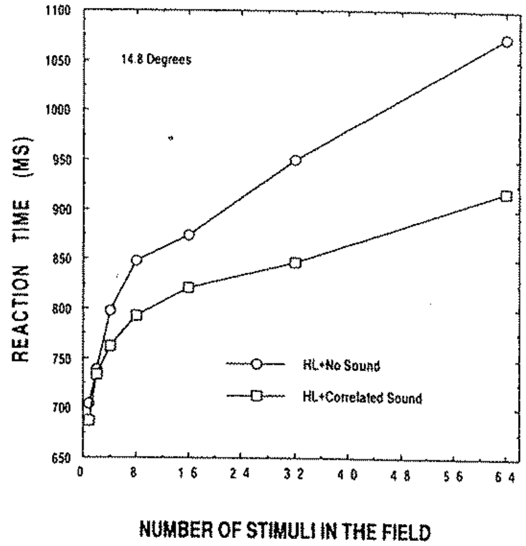

Figure 7. *Mean reaction time observed when the enhanced visual target was located 14.8 deg from the fixation point. A shift in gaze was probably required to identify which target was present. HL = highlight.*

from the initial line of gaze and when numerous distractor stimuli are present. As illustrated in Figure 7, this generalization seems to hold even when the target is enhanced. Here, as in Figure 6, performance was best when spatial information from the auditory channel was available (open squares). In the case in which 63 distractor stimuli were present, latencies were approximately 200 ms faster when the auditory signal was added.

The mean error rate in the spatially correlated sound condition in the current experiment was 1.2%. The mean error rate in the no-sound condition was 1.8%. Although an analysis of variance indicates that these differences are not statistically significant, $F(1,4) = 2.401, p > 0.05$, the no-sound condition produced the higher error rate. Clearly the latter observation is incompatible with an explanation dependent on the notion of a speed/accuracy trade-off favoring the spatially correlated sound condition.

GENERAL DISCUSSION

The presence of spatial information from the auditory channel can reduce the time required to locate and identify a visual target even when the target occurs within a restricted region around the initial line of gaze. Considering that the spatial resolution of the retina, at all points in this region, is at least 20 times more accurate than that observed in the auditory modality, the advantage generated in the visual search task by the spatially correlated sound continues to surprise us. These results replicate findings reported earlier from our laboratory (Perrott et al., 1990).

The current results extend our initial observations considerably. First, the reduction in latency obtained by providing auditory spatial information increases as a direct function of the visual load. Second, as previously demonstrated, the utility of the auditory spatial information also increases as a direct function of the distance of the target from the initial line of gaze. Third, there is a strong interaction between the number of events within the field and the relative distance of the target from the initial fixation point. The advantage of providing auditory spatial information is particularly evident when a substantial shift in gaze is required in the presence of a cluttered visual field. Thus in tasks in which multiple concurrent images are required or where more spatially extended arrays are desirable, we expect to see optimal conditions for the employment of auditory spatial information. Even for targets restricted to the central visual field, as in the current experiments, reduction in latency can be considerable (in excess of 300 ms).

That similar functions were obtained under conditions of visual enhancement of the target is, we think, important. This effect indicates that providing sound from the same location as the image to be sampled will be useful even in tasks in which substantially different visual events are arrayed in the field. It is interesting to note that the improvement in the localization and identification of the target required in the current two-alternative, forced-choice task involved an acoustic signal devoid of any information regarding the characteristics of the visual target itself. There is no obvious reason that this must be the case. One could imagine embedding information regarding the relative importance of the information at that location or even the type of function involved.

Finally, we obtained a rough estimate of the utility, measured in terms of visual search time, of the two possible methods of target enhancement used in Experiments 1 and 2, visual highlighting versus auditory correlated sound. This comparison must be viewed with caution because the number of subjects tested in each experiment differed. When the target was located at 0 deg in the absence of distractor stimuli, the mean search times in the auditory condition of Experiment 1 and the visual condition of Experiment 2 were nearly identical (528 vs. 530 ms). However, in the most demanding condition (target located at 14.8 deg and 63 distractor stimuli present), performance with a correlated sound was superior to performance with only visual highlighting (971 vs. 1073 ms). These results are similar to the aforementioned conclusions. There is no difference in visual search time between the correlated sound and visual highlighting for targets located in the observer's line of sight. The correlated sound reduced search time by roughly 100 ms for the extreme peripheral locations and maximum number of distractor stimuli present. Of course, the lowest search times, when produced with both methods of target enhancement, were used in Experiment 2.

REFERENCES

Doll, T. J., Gerth, J. M., Engelman, W. R., and Folds, D. J. (1986). *Development of simulated directional audio for cockpit applications* (USAF Report AAMRL-TR-86-014). Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory.

Gibson, J. J. (1950). *The perception of the visual world.* Boston: Houghton Mifflin.

Hormann, C. A., and Allen, J. D. (1987). An accurate millisecond timer for the Commodore 64 or 128. *Behavior Research Methods, Instrumentation, and Computers, 19,* 36–41.

Perrott, D. R., Saberi, K., Brown, K., and Strybel, T. Z. (1990). Auditory psychomotor coordination and visual search behavior. *Perception and Psychophysics, 48,* 214–226.

Thompson, S. L. (1987). The big picture. *Air and Space.* April/May, 74–83.

Wertheim, T. (1894). Uber die indirekte Sehscharfe [Concerning indirect visual acuity]. *Zeitschrift für Psychologie, 7,* 172–187.