A comparison of auditory monitoring performance in blind subjects with that of sighted subjects in light and dark*

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Two experiments were performed in which blind Ss, sighted Ss working in the dark, and sighted Ss working in the light were compared as to their efficiency on an auditory watchkeeping task. Absolute and differential auditory thresholds were measured in both experiments, and in the second experiment the groups also underwent a signal detection session under alerted conditions. There was some inconsistency as to relative performance of the sighted groups, but in both experiments the blind Ss were superior on the auditory watchkeeping task as to signals detected and effective sensitivity (d'). This difference was not attributable to a difference in auditory sensitivity or to a criterion adopted for responding. The groups in the second experiment did not differ significantly on the alerted signal detection task. Blind Ss' superior detection efficiency was attributed to the transfer of practiced variables related to more efficient utilization of auditory information.

Research and theoretical treatments of vigilance phenomena have been concerned primarily with the identification of variables that affect the vigilance decrement. In a 1963 review article, Bergum and Lehr categorized these factors as being task-related, environmental, or organismic. While the latter have been investigated with regard to individual differences in such things as age, sex, IQ, and personality, to the authors' knowledge there seem to be no vigilance studies comparing the performance of individuals having a sensory handicap (e.g., blindness) to that of normal Ss. Such a study would seem justified, since it is reasonable to expect that the mechanisms mediating auditory attention and the learned aspects of auditory discrimination are necessarily different for blind Ss who have learned to maintain alertness and to discriminate sensory signals without depending on visual input.

The blind have been found to be superior to sighted Ss on tactual form recognition tasks (Hunter, 1954; Foulke & Warm, 1967), in the comprehension of time-compressed speech (Foulke, 1964), and on sound localization (Seashore & Ling, 1918; Hayes, 1934) and echo-discrimination tasks (Ammons et al, 1953;

Dallenbach, 1951; Kellogg, 1962; Supa et al, 1944). While these results suggest that there might be some sort of sensory compensation by the blind for the loss of the visual modality, the results of several studies indicate that there are no differences in basic physiological sensitivity between blind and seeing persons.

Hayes (1934), in an early survey of "sensory compensation," concluded that absolute auditory thresholds were either higher for blind Ss or did not differ. Sakurabayashi et al (1956) found no differences in discriminations of loudness, pitch,

rhythm, timbre, or tonal memory using the Seashore Measure of Musical Talent Test. Robinson (1968), utilizing two signal detection tasks, found that blind and sighted Ss did not differ on the signal detection theory index of sensitivity, d' (see Swets, Tanner, & Birdsall, 1961). Curtis and Winer (1969) found that expert blind travelers exhibited an increased sensitivity to intensity differences in a 1-kc/sec pure tone, but that sighted Ss performed significantly better than the blind in making loudness discriminations of a broad-band noise. The authors found no differences in sensitivity to frequency changes between expert blind travelers and sighted Ss.

The superiority in the blind Ss' performance which does exist on the above-mentioned tasks has, in general, been interpreted in terms of practice effects. Because of greater dependence on, and use of, the auditory modality, the blind have learned to utilize various aspects of the available stimulus information more efficiently than sighted persons. When asked to perform a task which allows for the transfer of these practiced variables, the blind are typically superior.

Even though the stimulus information in the vigilance situation is typically minimal, there are certain reasons for hypothesizing that the task is ideally suited for the transfer of practiced variables related to auditory attention and discrimination. First, while the vigilance situation is monotonous for all Ss, it is perhaps not quite as monotonous for the blind Ss since they are less mobile than sighted Ss and more accustomed to

Fig. 1. Changes in hits (H) for each group in Experiment 1.

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Fig. 2. Changes in false alarms (FA) in Experiment 1.

sitting still and attending to auditory signals. Secondly, blind Ss' greater dependence on the auditory modality for afferent stimulation and maintenance of alertness might inadvertently increase the likelihood of detecting auditory signals.

Finally, dependence on the auditory system as a primary source for acquiring information about the environment gives the blind a great deal more practice in listening for and distinguishing the relevant or critical aspects of auditory stimulation under conditions of temporal uncertainty. This implies that signals with low signal-to-noise ratios occurring at irregular time intervals would be more readily perceived by blind listeners than by unpracticed sighted Ss. To the extent that these factors are operative and transferable to the vigilance situation, it is hypothesized that the performance of blind Ss will be superior to that of sighted Ss.

Two experiments, involving different Ss, were performed. Experiment 1 involved comparison of blind Ss, sighted Ss in the dark, and sighted Ss in the light on an auditory vigilance task as well as comparison of conventional absolute and differential thresholds of these groups. Experiment 2 was a partial replication in which analogous groups were compared in terms of absolute and differential thresholds, and auditory vigilance performance. In addition, Ss

in the second experiment also performed a signal detection task in order to determine whether or not the performance differences which existed under conditions of temporal uncertainty characteristic of the vigilance task also existed under the highly alerted conditions of the signal detection situation.

EXPERIMENT 1 Method

Subjects. Thirty Ss, unselected as to sex, served in Experiment 1. Ten of these were totally blind (i.e., had no light perception). They were recruited from the general population of the Louisville metropolitan area and ranged in age from 25 to 58 with a median age of 37. The remaining Ss were students at the University of Louisville. One group of 10 sighted Ss, performing the vigilance task in light (Ss IL), ranged in age from 19 to 21 with a median of 20; the other group, sighted Ss performing in the dark (Ss ID), ranged from 18 to 20 with a median age of 20. All Ss were paid \$2.50 for participating and an incentive award of \$25.00 was offered to the S with best performance overall.

Apparatus and procedure. The output of a Grason-Stadler noise generator was fed through a General Radio decade attenuator and a system of BRS logic circuitry into Grason-Stadler HD 30 earphones worn by S, who was seated in a

Model 402 A soundproof room.

In the initial stage of the experiment, Ss' absolute thresholds for a white-noise pulse were measured by the method of limits. After this the output level was set 60 dB above S's threshold (SL). The BRS circuitry was then set so that the noise was alternately switched on for periods of 0.5 sec and off for periods of 2.0 sec. Occasionally, louder signal pulses occurred, which were 61.8 dB (SL) in intensity. The average signal rate was 2/min, but they occurred randomly with the restrictions that the intersignal interval was never less than 10 sec or more than 50 sec, and 20 signals occurred within each 10-min interval. Signal occurrence was determined by a Gerbrands filmstrip programmer.

Following the absolute threshold determination, Ss underwent a 15-min practice session. They were told to respond rapidly (by depressing a telegraph key) whenever a signal occurred. If they failed to detect a signal within the 2 sec following its termination, a miss was tabulated, and if they reported a signal at other times, a false alarm was scored. In the 15-min practice session, feedback was given to S by informing him when a signal had occurred, allowing time for him to make a response.

Following practice, all Ss participated in an 80-min vigilance session. Dependent measures were detections or hits (H), false alarms (FA), derived measures of S sensitivity (d'), and conservatism (β). (See Green & Swets, 1966, for a discussion of the measures and Freeman, 1964, for the procedures employed in computing the measures.) There are difficulties in applying signal detection theory (SDT) concepts to vigilance data (Jerison et al, 1965), but it was felt that some insight into the nature of observed differences might be gained.

At a time subsequent to the vigilance session, Ss' differential thresholds were measured. This was an afterthought; it was done because the groups differed in absolute threshold, and it seemed desirable to determine whether or not this influenced their differential thresholds. For this procedure, the noise generator was fed through a Grason-Stadler electronic switch, a Daven attenuator, and then into the attenuator previously described. In the A channel of the electronic switch the level was 60 dB (SL); in the B channel, it was attenuated. The switch was internally cycled, and time in each channel was 0.5 sec. S reported that the noise was steady or fluctuating. The Daven attenuator was adjusted in 0.1-dB steps until the judgment changed from "steady" to "fluctuating" or the

Fig. 3. Changes in the SDT index of sensitivity (d') in Experiment 1.

reverse. Differential thresholds were computed by conventional procedures.

Results

Blind Ss were found to have absolute thresholds 6.8 dB higher than normals, and an analysis of variance indicated that the difference was significant ($p < .01$). The difference in DLs for the two groups was very small and not statistically significant.

Figure 1 shows mean percent H for successive 10-min time blocks. The analysis of variance of H showed significant effects due to visual status ($p < .001$). Orthogonal comparisons

were computed on the variance attributable to visual status to determine whether or not effects due to blindness were significant. Results indicated that blind Ss detected more signals than sighted Ss ($p < .001$) and that Ss in light (IL) detected more signals than Ss in dark (ID) ($p < .025$). Significant effects due to time on task ($p < .001$) and to the Visual Status by Time interaction ($p < .05$) were also found.

Figure 2 shows mean FAs for successive blocks of time. The analysis of variance revealed that effects due to visual status were not significant.

Fig. 4. Changes in β in Experiment 1.

However, because the FA data did not appear to be normally distributed, a Kruskal-Wallis one-way analysis of variance by ranks was computed. On this test, the three groups differed significantly ($p < .01$). The IL group made the most FAs; the ID group, the least. Effects due to time in the main analysis were also significant ($p < .001$), but the interaction was not.

The analysis of variance of the d' data showed that effects due to visual status were significant ($p < .001$), but that the two sighted groups did not differ from each other. Sensitivity declined as time on task increased ($p < .05$). The interaction was not significant.

Figure 3 shows the temporal trend for d' . It is immediately apparent that blind Ss were superior to both groups of sighted Ss on the index of sensitivity and that sighted Ss did not differ from each other.

Figure 4 shows the trend for β over time. Originally the data were analyzed by a conventional analysis of variance—a questionable procedure, as the data, being ratios, were skewed. Indications were that the difference between groups was not significant, though the means for the ID group were generally highest and for IL, lowest. There was a significant variance over time blocks ($p < .05$), but not a differential trend for the three groups. Because of the nonnormality of the data, a Kruskal-Wallis analysis of variance by ranks was also employed. The differences approached significance ($.05 < p < .10$).

Discussion

A recapitulation of the findings would state that blind Ss were characterized by a higher hit rate than the sighted groups, a false alarm rate lower than the sighted group in light and comparable to the sighted group in the dark, a higher sensitivity index (d') than the sighted groups, and an index of conservatism (β) generally falling between that for the sighted group in light (lowest) and that in the dark (highest). Since the blind Ss were lower in absolute auditory sensitivity than sighted Ss and comparable to them in differential sensitivity, it is doubtful that this reflects a true sensory difference.

Possibly placing sighted Ss in the dark lowers their arousal level and general tendency to respond—thus decreasing hits and false alarms. On the other hand, sighted Ss in light make more false alarms than the other groups as well as somewhat more hits than the sighted in dark and appreciably fewer than the blind Ss. Thus, they too had lower effective

Table 1
Mean Hits, False Alarms, d' , and Log β for Signal Detection Session

		Feedback	No Feedback	Total
Mean Percent Hits	Blind	83	88	86
	Light	76	77	77
	Dark	80	80	80
Mean Percent False Alarms	Blind	43	36	35
	Light	39	31	35
	Dark	41	35	38
Mean d'	Blind	1.19	1.65	1.42
	Light	1.06	1.41	1.23
	Dark	1.10	1.27	1.19
Mean Log β	Blind	-.52	-.71	-.62
	Light	-.17	-.15	-.16
	Dark	-.29	-.29	-.29

sensitivity than the blind Ss but maintained a higher hit rate than the ID group at the cost of a higher FA rate—i.e., their criterion for responding (β) was lower.

One can only speculate about the finding that blind Ss had a higher sensitivity (d') on the vigilance task. It may be that such Ss are more accustomed to monotony and restriction of movement and that because of the usual poverty of their environmental stimulation, they find the vigilance situation more interesting—or less traumatic. It is equally likely that having had a great deal more experience distinguishing critical aspects of auditory stimulation gives blind Ss an advantage which transfers to the vigilance task.

Experiment 2 was designed to extend and replicate in part Experiment 1. It was hypothesized that blind Ss would be superior to sighted Ss on a vigilance task but not on an alerted signal detection task similar to the watchkeeping task.

EXPERIMENT 2

Method

Subjects. Again there were 30 Ss, 10 totally blind and 20 sighted. The blind Ss ranged in age from 19 to 45, with a median age of 24. The ID group in this experiment, comparable to that in Experiment 1, ranged in age from 17 to 20, with a median age of 19; the IL group ranged from 16 to 33, with a median of 19. All Ss were paid for their performance and a monetary prize for "best performance" was awarded as well.

Apparatus. Generally, apparatus in Experiment 2 was the same as that in Experiment 1, though there were minor alterations in the switching circuits employed for the signal detection phase of the experiment.

Procedure. Absolute and differential thresholds were determined as in Experiment 1. Ss then participated in a "signal detection" session in which they listened for 200 trials to two 1-sec Gaussian noise pulses separated by a 1-sec silent interval and indicated

whether the noise pulses were "the same" or "different." On half the trials, randomly determined, the second pulse was 61 dB (SL) and the first was 60 dB (SL); on half, both pulses were 60 dB (SL). During the first 100 trials, feedback was provided. Following these, a 3-min rest period was given, then the second 100 trials without feedback. Both the ID and IL sighted Ss performed this part of the experiment in light. Detections and false alarms were tabulated and the usual TSD indices, d' and β , were determined as previously described. However, in this experiment the β s were converted to natural logarithms so that their distribution would be sufficiently close to normal for conventional analysis.

Results

Preliminary measures. The groups did not differ significantly in either absolute threshold (in which the maximum difference between groups was 2 dB) or differential threshold (maximum difference, 0.1 dB). The

findings for the alerted signal detection task, which are more complex, are shown in Table 1. Note that blind Ss seem to detect more signals, that they have a somewhat greater propensity to make false alarms, a higher sensitivity index (d'), and a lower conservatism index (β). Analysis of variance of the signal detection data, however, revealed that the variance between groups only approached significance for detections ($p < .10$) and was not significant for false alarms or d' . The variance between groups for log β ($p < .05$) was significant. Note, too, that in the second 100 trials, in which no feedback was given, following the first 100 trials in which there was feedback, there is an apparent small increase in detections, an appreciable decrease in false alarms, an increase in d' , and little change in log β . The changes in false alarms and d' are significant ($p < .01$). In summary, then, there are clear differences in the groups only in criterion (β). Changes as a function of feedback and/or practice are seen primarily in false alarms and thus sensitivity, d' .

Vigilance session. Figure 5 shows the detections over time for each group. As in Experiment 1, the blind Ss detected more signals. Appropriate analysis of variance and orthogonal comparisons indicate that the groups differ generally ($p < .05$), that the blind group differs from the others ($p < .01$), but the sighted groups did not differ significantly. Effects due to time were significant ($p < .01$), but the interaction was not.

Figure 6 shows similar means for the false alarms. The rank orders of groups in Experiment 1 were not

Fig. 5. Changes in hits (H) for each group in Experiment 2.

Fig. 6. Changes in false alarms (FA) in Experiment 2.

maintained, and neither a conventional analysis of variance nor Kruskal-Wallis analysis indicated that the groups differed significantly. There were, as usual, significant declines over time for all groups ($p < .01$), but no indications of differences in such declines.

In Figure 7, mean d' values are plotted over time for each group. The blind Ss had the highest d' means, as in Experiment 1, but whereas in Experiment 1 the two sighted groups had nearly identical means, in the present experiment the IL means fall

between the ID and blind means. An analysis of variance indicated significant differences between groups ($p < .01$), and orthogonal comparisons indicated a difference between the blind Ss and both groups of sighted Ss ($p < .01$). The difference between the sighted Ss approached significance ($.05 < p < .10$). Sensitivity (d') declined over time ($p < .05$) but not differentially.

Figure 8 shows the mean conservatism indices ($\log \beta$). It is apparent that they increased over

Fig. 7. Changes in the SDT index of sensitivity (d') in Experiment 2.

time, as they generally do. While the IL means were generally low in Experiment 1, in Experiment 2 they are generally high. Analysis of variance indicated no significant differences between groups, though the general increase over time is significant ($p < .01$).

In summary then, the significant differences between groups in the vigilance session of Experiment 2 denoted superiority of blind Ss in detections and sensitivity (d'). The usual temporal trends were observed for all four dependent measures but did not differ across groups.

Correlations: Signal detection and vigilance. Since Ss in Experiment 2 underwent signal detection sessions under alerted conditions (hereafter termed simply "signal detection") and under conditions of temporal uncertainty (hereafter termed simply "vigilance"), it appeared reasonable to try to determine by correlational techniques if there were common factors in the two situations. It should be remembered, however, that the signal magnitude was smaller in the signal detection situation and, when interpreting the correlation, that there were only 10 Ss in each group.

Table 2a shows the correlations, with Ss pooled for all three groups, between total signal detection scores and vigilance scores in each block of time of the vigilance session and for the entire session. It is noteworthy that appreciable and generally significant correlations were obtained for detections and d' for the entire session and throughout the session, though there appears to be some tendency for the d' correlation to be less later in the session. For false alarms and $\log \beta$, however, the overall correlation and most other correlations were not significant, but significant correlations were obtained for the first time block. The latter finding may reflect the fact that false alarms decline rapidly and later in the session may be so few that they provide an unreliable index of performance.

Table 2b shows correlations between total signal detections and total vigilance scores on the four measures for each group of Ss. Note that for the sighted groups, the correlations are appreciable but that for the blind Ss the correlations are quite low. However, only one correlation (0.69, for correlations of d' s for the IL Ss) was significant beyond the 0.05 level. It seems probable that had more Ss been run per group, similar correlations would have been obtained and they would be significant for the sighted Ss, but this is conjecture. Such a result would suggest that for sighted Ss, a signal

Fig. 8. Changes in natural logarithms of β in Experiment 2.

detection score is a reasonable predictor of performance in the vigilance situation but that this is not true for blind Ss.

GENERAL DISCUSSION

With regard to the vigilance decrement, the present results are in agreement with previous findings. In both experiments, hits, false alarms, and d' decreased over time while β increased. Of greater interest with regard to the present discussion is the superiority of the blind Ss' performance in terms of signals detected and effective sensitivity. This difference cannot be attributed to "sensory compensation" or heightened physiological sensitivity, since there were no differences in absolute or differential thresholds and no

comparable increase in blind Ss' capability to detect signals under the alerted conditions of the signal detection task.

Still unanswered is the question as to the reason for the blind Ss' superior detection efficiency. The difference is not due to the presence of distracting visual input for sighted Ss and the absence of such input for blind Ss, since both the ID and IL sighted Ss were inferior. It might be argued, of course, that varied visual input and no visual input (darkness) are distracting to a sighted S, whereas the latter condition is one to which a blind S has adapted, but this post hoc argument is not too appealing.

Another possibility is that the sighted Ss, being college sophomores, were more sophisticated about

psychological experimentation and therefore more blasé and less conscientious than the blind Ss, who were selected from the general population and were not used in other experiments. This would not explain why the groups were more or less equal on false alarms, in auditory acuity, and on signal detection tasks under alerted conditions, but perhaps these indices seemed less important to the Ss (in the first case) or required less sustained effort (in the second and third cases). To check this hypothesis, it would be necessary to replicate these experiments and draw all Ss from the general population.

What appears to be most credible is an explanation for the blind Ss' superior detection efficiency in terms of the transfer of practiced variables to the vigilance situation. Since blind Ss have no really rich source of information other than the auditory channel, they have not only learned to rely on it more continuously than can sighted Ss, but they have also had a great deal more practice listening for and discriminating critical aspects of auditory stimulation under conditions of temporal uncertainty. Thus, one might expect signals with low signal-to-noise ratios occurring at irregular time intervals to be more readily perceived by blind listeners than by unpracticed sighted Ss.

It is not being suggested that blind Ss, through practice, have learned to utilize sensory information in a way that would be impossible for sighted Ss to learn. On the contrary, there is evidence that sighted listeners can improve their sensitivity (d') over sessions (Binford & Loeb, 1966). The authors suggested that Ss gradually learn enough about the stimulus characteristics of the signal and nonsignal pulses so that they become less frequently confused. It is suggested that this is the kind of discrimination learning with which blind Ss have had more practice and that this transfers to the vigilance task.

Blind Ss' superiority over sighted Ss in using the auditory modality has been demonstrated not only on the vigilance task, but also on other tasks, such as echo discrimination and localization. In accounting for this difference, the hypothesis of sensory compensation has been ruled out. Since their superiority on various perceptual tasks has been attributed to the transfer of practiced or learned variables related to more efficient utilization of sensory information, it is suggested that the term "perceptual compensation" be substituted for "sensory compensation" when referring to the various ways in which blind persons have demonstrated superiority in using their auditory modality.

Table 2
Correlations Between Signal Detection and Vigilance

	Vigilance Time Block								Total
	1	2	3	4	5	6	7	8	
A. Correlations Across Groups									
Percent Hits	.38	.41	.45	.49	.45	.53	.43	.35	.37
Percent FA	.48	.22	.16	.19	.29	.08	.15	.25	.30
d'	.60	.32	.36	.55	.42	.41	.34	.35	.42
Log β	.40	.31	-.01	.26	.01	-.03	-.01	.17	.17

With $df = 28$, for significance at the .05 level, an r of .36 is needed; for significance at the .01 level, an r of .46 is needed.

	Blind		Light		Dark	
B. Correlations Within Groups						
Percent Hits		-.13		.56		.39
Percent FA		.07		.47		.52
d'		.01		.69		.39
Log β		-.13		-.04		.60

With $df = 8$, for significance at the .05 level, an r of .63 is needed; for significance at the .10 level, an r of .55 is needed.

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