Effects of Aircraft Noise on Vigilance Performance and Perceived Workload

Ami B. Becker, Joel S. Warm, William N. Dember, JoAnn Sparnall, Laura DeRonde
University of Cincinnati
and Peter A. Hancock
University of Minnesota

This study examined the effects of exposure to intermittent jet aircraft noise played through stereophonic speakers (70dBA or 95dBA maximum intensity) on performance efficiency and perceived workload in a 40-min visual vigilance task. The noise featured a Doppler-like quality in which planes seemed to approach from the monitor's left and recede to the right. Performance in noise, measured in terms of perceptual sensitivity (d'), was significantly poorer than in a quiet condition. Moreover, in comparison to subjects performing in quiet, those who operated in noise were less able to profit from knowledge of results (KR) regarding performance efficiency. In addition to its negative effects upon signal detectability, noise significantly elevated perceived workload, as indexed by the NASA-TLX. This effect was robust; it was not mitigated by KR, even though KR served generally to reduce the overall level of perceived workload in the study. The consistency of the effects of noise in regard to both performance efficiency and perceived workload challenges a recent conclusion offered by Koelega and Brinkman (1986) that lawful relations are not observable in studies of the effects of noise on vigilant behavior.

INTRODUCTION

Recent evidence mandates a revision in the traditional view that vigilance tasks place a minimal information processing load upon monitors (cf. Dember and Warm, 1979). Much of this evidence comes from measurements of perceived mental workload, or the processing resources required by a task, through the use of a multidimensional scale known as the NASA Task Load Index (TLX, Hart and Staveland, 1988). The scale provides an index of overall workload (range: 0 to 100) and also identifies the relative contributions of six sources of workload, Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration.

Investigations using this instrument have demonstrated that the cost of mental operations in vigilance is substantial. Overall workload scores in these studies reached the upper level of the scale, with Mental Demand and Frustration the primary contributors to workload (Becker, Warm, Dember and Hancock, 1991; Warm, in press; Warm, Dember, and Parasuraman, 1991). Moreover, workload ratings in vigilance have been related to task factors affecting performance efficiency. For example, the quality of vigilant behavior varies directly with signal salience and inversely with event rate (Warm and Jerison, 1984), and workload ratings have been found to parallel these effects, varying inversely with salience and directly with event rate (Galinsky, Dember and Warm, 1989; Gluckman, Warm, Dember, Thiemann and Hancock, 1988). As is generally the case with subjective reports, the fact that workload ratings can be brought under experimental control enhances the validity of such ratings (Natsoulas, 1967).

The present study continues this line of investigation by examining the effects of an environmental factor - noise - on perceived workload in a vigilance task. As described by Loeb (1986), noise is perhaps the most ubiquitous pollutant and a major environmental stressor in our industrialized society. It has also been studied extensively in relation to vigilance performance (Davies and Parasuraman, 1982; Hancock, 1984; Smith, 1991). In general, the quality of vigilant behavior is degraded when subjects must perform tasks requiring high information-processing demands in the presence of high levels (90dBA or more) of intermittent noise. Under such conditions, it is conceivable that noise will also elevate the perceived workload of the vigilance task, especially in light of Cohen's (1978) argument that subjects must expend processing resources in order to compensate for the distracting effects of noise.

Previous studies on the implications of noise for vigilance performance have, for the most part, neglected to

investigate factors which might mitigate the adverse effects of noise. One such candidate is knowledge of results (KR) or feedback concerning signal detections. KR has been found to have a powerful effect upon vigilance performance (Warm and Jerison, 1984). A recent study by Becker, et al. (1991) using a signal detection theory approach, has shown that KR about correct detections (Hit-KR) considerably enhanced subjects' perceptual sensitivity to critical signals in a data-limited vigilance task and that such KR also reduced the perceived workload associated with that task. Accordingly, a second goal of this study was to determine if Hit-KR can mitigate the effects of noise upon vigilance performance and perceived workload.

METHOD

Three levels of noise (Low intensity, High intensity and a No-noise control) were combined factorially with two KR conditions (Hit-KR and a No-KR control). Twelve subjects (equated for gender) were assigned at random to each of the six resultant experimental cells.

All subjects participated in a 40-min vigil divided into four continuous 10-min periods of watch. While seated alone in an Industrial Acoustics sound chamber, they monitored repetitive flashes (150 msec) of a vertically oriented line (2 X 32 mm) on a VDT for occasional increments in the height of the line (3mm). The lines appeared at a rate of 30 events/min in all conditions, with a signal probability of .033. Feedback was provided to the Hit-KR group in the form of a block of stars which appeared on the VDT for 200 msec immediately following a correct detection. The stars appeared after each response for subjects in the No-KR group, thus controlling for added stimulation but carrying no evaluative information. Subjects indicated their detection of critical signals by pressing the spacebar of a microcomputer, which also orchestrated the presentation of stimulus events and provided the star display to the two KR groups as appropriate. Perceived workload was assessed by a computerized version of the TLX immediately upon the conclusion of the vigil.

The recorded sound of jet engines, played through stereophonic speakers in the testing chamber, provided a dynamic source of intermittent noise. The noise featured a Doppler-like effect, in which planes seemed to approach from the listener's left and then move away to the right. This was achieved by having engine sounds rise and fall in intensity during a noise episode. Episode durations ranged from 17.91 to 42.90 sec (M = 26.89 sec, SD = 9.33) sec; inter-episode intervals ranged from 4.90 to 12.25 sec (M = 6.98 sec, SD = 2.71 sec). Times to reach maximum amplitude within an episode ranged from 6.47 to 16.13 sec (M= 10.28 sec, SD = 2.94 sec). Decay times from maximum amplitude to quiet ranged from 9.36 sec to 25.12 sec (M = 16.48 sec, SD = 5.79). Maximum amplitudes at the subject's ear in the low intensity and high intensity conditions were 70 dBA (approximately the loudness of a normal automobile) and 95 dBA (approximately the loudness of a subway train), respectively.

RESULTS

An analysis of variance (ANOVA) of the perceptual sensitivity scores (d') revealed that noise had a degrading effect upon overall signal detectability; M's for the No-noise, Low-noise, High-noise conditions were 1.97, 1.80 and 1.50, respectively, F (2, 66) = 4.25, p <.018. In addition, the analysis revealed that KR enhanced the overall level of signal detection; M's for the Hit-KR and No-KR conditions were 2.16 and 1.35, respectively, F (1, 66) = 36.82, p <.0001. This effect was modified by noise, F (2, 66) = 3.61, p <.03. The Noise X KR interaction is presented in Figure 1. Tests of the

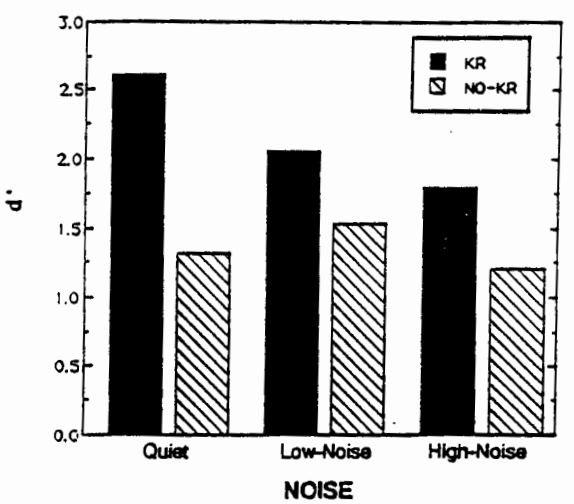

Figure 1. Perceptual sensitivity for the KR and No-KR conditions in the context of three noise conditions.

simple effects of KR within each of the three noise conditions resulted in significant differences in all comparisons, F (1, 66) > 5.0, p <. 05 in each case. However, as can be seen in the figure, the beneficial effects of KR were greater in the control than in the noise conditions. As has been found in several other vigilance experiments (cf. Parasuraman, Warm, and Dember, 1987), perceptual sensitivity declined significantly over the course of the watch; M's for periods 1-4 were 1.81, 1.90, 1.69 and 1.62, respectively, F (3, 198) = 5.02, p <.02. However, neither noise nor KR had any significant impact upon the vigilance decrement (all interactions involving time on task were not significant, p >.05). An ANOVA of the response criterion scores (β) revealed that subjects also became significantly more conservative over time; M's for periods 1-4 were 2.11, 3.80, 4.90, and 5.13, respectively, F (3, 198) = 7.77, p <.001, a result which is typical in vigilance studies (cf. Parasuraman, et al., 1987). The effects of noise and KR on the criterion scores were unremarkable (all components of variance involving these factors were nonsignificant, p >.05).

The effects of noise and KR on perceptual sensitivity were mirrored in the overall workload scores. Overall workload for the Hit-KR condition (M = 62.83) was significantly less than in the No-KR condition (M = 75.86), F (1,66) = 14.23, p <.0003. As can be seen in Figure 2, overall workload was higher in noise than in quiet, and this impression was confirmed by the statistical analysis, F (2, 66) = 3.27, p <.04.

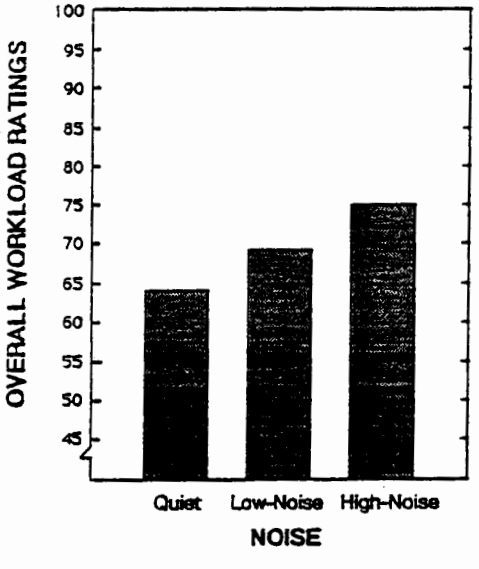

Figure 2. Mean overall workload ratings for three noise conditions.

An ANOVA of the data for the TLX subscales revealed that there were significant differences in the components of workload, F (4, 264) = 26.07, p <. 001, and that these differences were invariant across the experimental conditions (none of the interactions between subscales and the dimensions of noise and/or KR was significant). As illustrated in Figure 3, Frustration and Mental Demand were the principal contributors to workload.

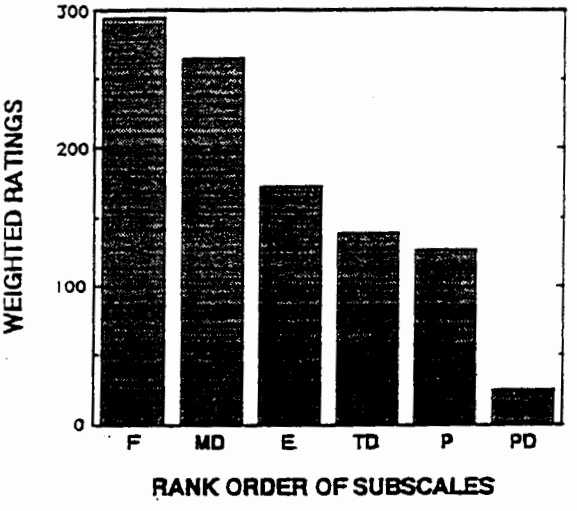

Figure 3. Relative contribution of the six workload dimensions to the vigilance task (F=Frustration, MD=Mental Demand, E=Effort, TD=Temporal Demand, P=Performance, PD=Physical Demand).

DISCUSSION

This study provides strong evidence for the role played by noise as an environmental stressor in vigilant behavior. On a performance level, noise generally degraded the subjects' perceptual sensitivity to critical signals. Contrary to expectation, providing subjects with Hit-KR did not mitigate this effect. Instead, noise acted to suppress the effects of KR, i.e., the degree to which feedback was associated with enhanced signal detectability. As suggested by Becker, et al. (1991), the beneficial effects of KR in a data-limited type task, such as that used here, may come from its ability to augment signal definition.

Given Cohen's (1978) argument that noise drains processing resources, the Noise X KR interaction noted in this study may reflect the consequences of such a drain on the subjects' ability to process the cues to signal definition otherwise provided by KR.

In addition to its effects on performance efficiency, noise also elevated subjects' perceptions of the workload imposed by the vigilance task. This effect was robust; it was independent of the influence of Hit-KR, although such KR served generally to reduce overall perceived workload. The workload results are important. They indicate that subjects can access and report subjective experiences of workload in vigilance tasks, and that these experiences are closely tied to both task and environmental factors which influence performance efficiency. In this sense, the present study provides additional support for the validity of the TLX as a workload measure in sustained attention tasks. Moreover, the consistency of the effects of noise in relation to both perceived workload and signal detectability challenges the conclusion reached in an influential paper by Koelega and Brinkman (1986) that lawful relations are not observable in studies of the effects of noise on vigilant behavior.

While the overall workload scores of the TLX were modified by both noise and Hit-KR, the subscale scores were not affected. The similarity in the pattern of those scores in all experimental conditions is consistent with the earlier findings of Becker, et al. (1991), implying that there may be a typical workload profile which reflects the particular demands imposed by vigilance tasks. While the absolute magnitude of overall workload may vary as a result of experimental conditions, the factor loadings of specific workload components seem to remain relatively fixed, with Frustration and Mental Demand serving as the primary components.

REFERENCES

Becker, A.B., Warm, J.S., Dember, W.N. and Hancock, P.A. (1991). Effects of feedback on perceived workload in vigilance performance. Proceedings of the Human Factors Society 35th Annual Meeting (pp. 1491-1494). Santa Monica, CA: Human Factors Society.

Cohen, S. (1978). Environmental load and the allocation of attention. In A. Baum, J.E. Singer, and S. Valins (Eds.), Advances in environmental psychology (Vol. 1, pp. 1-29). Hillsdale, NJ: Erlbaum.

Davies, D.R., & Parasuraman, R. (1982). The psychology of vigilance, London: Academic Press.

Dember, W.N., and Warm, J.S. (1979). The psychology of perception (2nd ed.). New York: Holt, Rinehart and Winston.

Galinsky, T.L., Dember, W.N., and Warm, J.S. (1989, March). Effects of event rate on subjective workload in vigilance performance. Paper presented at the meeting of the Southern Society for Philosophy and Psychology, New Orleans, LA.

Gluckman, J.P., Warm, J.S., Dember, W.N., Thiemann, J.A., and Hancock, P.A. (1988, November). Subjective workload in simultaneous and successive vigilance tasks. Paper presented at the meeting of the Psychonomic Society, Chicago, IL.

Hancock, P.A. (1984). Environmental stressors. In J.S. Warm (Ed.), Sustained attention in human performance (pp. 103-142). Chichester, UK: Wiley.

Hart, S., and Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P.A. Hancock and N. Meshkati (Eds.), Human mental workload (pp. 139-183). Amsterdam: Elsevier.

Koelega, H.S., and Brinkman, J.A. (1986). Noise and vigilance: An evaluative review. Human Factors, 28, 465-481.

Natsoulas, T. (1967). What are perceptual reports all about? Psychological Bulletin, 67, 249-272.

Parasuraman, R., Warm, J.S., and Dember, W.N. (1987). Vigilance:Taxonomy and utility. In L.S. Mark, J.S. Warm, and R. L. Huston (Eds.), Ergonomics and human factors: Recent research (pp. 11-32). New York: Springer-Verlag.

Smith, A.P. (1991). Noise and aspects of attention. British Journal of Psychology, 82, 313-324.

Warm, J.S. (in press). Vigilance and target detection. In B.M. Huey and C.D. Wickens (Eds.), Teams in transition. Washington, DC: National Academy Press.

Warm, J.S., Dember, W.N., and Parasuraman, R. (1991). Effects of olfactory stimulation on performance and stress in a visual sustained attention task. Journal of the Society of Cosmetic Chemists, 42, 199-210.

Warm, J.S., and Jerison, H.J. (1984). The psychophysics of vigilance. In J.S. Warm (Ed.), Sustained attention in human performance (pp. 15-59). Chichester, UK: Wiley.

Becker, A.B., Warm, J.S., Dember, W.N., Sparnall, J.A., DeRonde, L., & Hancock, P.A. (1992). Effects of aircraft noise on vigilance performance and perceived workload. Proceedings of the Human Factors Society, 36, 1513-1517.