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Head restraint enhances visual monitoring performance

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Subjects monitored a visual display for occasional increments in the horizontal movement of a bar of light. When the display was viewed without head restraint, detection probability was directly related to the amplitude of the increments in movement which constituted critical signals and inversely related to background event rate (the frequency of neutral events in which critical signals were embedded). When positioning of the head was restrained by a headrest, the detectability of low-amplitude signals was enhanced considerably and the influence of background event rate was attenuated. The results are considered as providing further support for the importance of sense mode coupling in visual monitoring.

An important feature of most visual monitoring tasks is the loose coupling between the observer and the display to which he must attend. Typically, observers are free to make responses, involving head and eye movements, that are incompatible with viewing the display, and evidence is accumulating to indicate that such responses are a factor in performance efficiency. For example, Mackworth, Kaplan, and Metlay (1964) and Schroeder and Holland (1968) have shown that the frequency and patterning of eye fixations is related to the detection of critical signals. Another illustration of the importance of coupling and observing activities comes from an experiment by Hatfield and Loeb (1968) in which observers were required to detect large changes in the illumination level of pulsed stimuli. These investigators devised a means to eliminate eye blinks and eye movements by taping the subjects eyelids shut with transparent plastic tape and having them observe illumination changes through closed eyelids. Detection probability was greater in this condition than in a control condition in which free observing was possible.

The study to be reported here evolved from an effort to extend this line of investigation. Our initial purpose was to examine eye scanning activity in relation to variations in two stimulus attributes known to have a strong influence on monitoring efficiency. One of these was critical signal amplitude—the degree to which critical signals exceed threshold values. The other, was the rate of repetitive stimulation or background event rate—the frequency of presentation of neutral events that occasionally become critical signals. An abundant amount of data is available to show that performance efficiency in vigilance tasks is directly related to signal amplitude (Metzger, Warm, & Senter, 1974; Wiener, 1964) and inversely related to the number of neutral events that the subject must monitor in search of critical signals (Guralnick, 1972; Jerison & Pickett, 1964; Krulewitz, Warm, & Wohl, 1975; Loeb & Binford, 1968; Metzger, Warm, & Senter, 1974). While observing responses have been implicated in mediating these effects (Jerison, 1970), no attempt has been made to measure such responses directly in this regard.

Our attempt to study observing activity was made with a Biometrics recording system which measures eye movements by use of a noncontacting photoelectric technique. The instrument consists of a sensing assembly mounted on a spectacle frame, an electronics package, and a headrest to restrain head movements. Preliminary work with this system produced a surprising result; the usual effects associated with variations in signal amplitude and event rate were absent when subjects monitored a visual display while harnessed in the system, but they were clearly evident when the system was not used.

It is especially noteworthy that all previous investigations concerned with signal amplitude and event rate have permitted unrestrained viewing in the vigilance situation. By contrast, head restraint was a necessary element in the eye-movement recording procedure that we employed. Head restraint can be considered as a possible means of achieving closer coupling between the observer and the monitored

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display. Accordingly, this experiment was designed to provide a systematic examination of the role of head restraint in relation to the effects of critical signal amplitude and event rate on monitoring efficiency.

METHOD

Subjects

One hundred and twenty students, 64 men and 56 women, from the University of Cincinnati served as subjects in order to fulfill a course requirement. None of the students had had prior experience with monitoring experiments.

Design

Critical signals of low and high amplitude were combined factorially with slow (6 events/min) and fast (21 events/min) background event rates and restrained and unrestrained viewing conditions to provide a total of eight experimental groups. Fifteen subjects were assigned at random to each group. All subjects participated in a 45-min vigil divided into three 15-min periods of watch.

Apparatus and Procedure

The subjects monitored the apparent movement of an 18 x 2 mm bar of red light which traveled along a horizontal vector within an 18 x 32 mm window. The window was centered within the lower half of a 61 x 61 cm flat-black panel. Apparent movement of the light bar was produced by successively illuminating small, and appropriately placed, Plexiglas diffusing screens. A neutral event, to which no overt response was required, was a pair of movements in which the bar moved 24 mm to the right (movement time, 0.60 sec), snapped back to its start position (where it remained for 0.80 sec), again moved 24 mm to the right (movement time, 0.60 sec), and then snapped back to its start position, where it remained for the ensuing interevent interval. Slow and fast event rates of 6 and 21 events/min were produced by setting the interevent intervals at 9.60 and 0.90 sec, respectively.

Critical signals for detection were increases in the second deflection within a pair of movements. Incremental excursions corresponding to the two levels of critical signal amplitude were 2 mm (24 to 26 mm) in the low-amplitude condition and 8 mm (24 to 32 mm) in the high-amplitude condition. These values represent increments of 8.3% and 33% of the base movement, respectively. An 18 x 1.5 mm white sight bar was positioned in vertical alignment 23 mm from the left end of the window in the display. The depth separation between the sight bar and the display was 6 mm. The sight bar served to mark the end of a nonsignal deflection. With a two-alternative forced choice psychophysical procedure, high- and low-amplitude critical deflections were essentially always detected by alerted subjects under both event rates. The observer indicated his detection of a critical signal by pressing a handheld microswitch. The moving bar display used in this study was adopted from Jerison and Pickett (1964). It is designed to minimize memory demands as to the nature of a critical signal by having all the information needed to make a paired-comparison judgment available within an event.

Five critical signals were presented in each period under all experimental conditions. The intervals between critical signals (intersignal intervals) were 30, 105, 180, 255, 330 sec. Fifteen random orders of signal presentations were prepared, with the restriction that each intersignal interval appear once and only once per 15 min of watch. Within each experimental group, each subject experienced one of these signal schedules as he progressed through the session.

Stimulus event rates and the occurrence of critical signals were controlled by solid state programming equipment and a Gerbrands punched-tape timer. The subjects' responses were recorded on two ITT electronic counters. Responses occurring within 2.5 sec after the onset of critical signals were recorded automatically as correct detections; all others were considered as errors of commission or false alarms. The 2.5-sec cutoff value was based upon previous work with this display (Krulewitz, Warm, & Wohl, 1975; Metzger, Warm, & Senter, 1974), which indicated that if a subject were going to respond to a critical signal, he would do so within this period of time.

The display to be monitored was mounted at eye level in the wall of a 1.5 × 1.5 × 2.1 m acoustically shielded chamber. The subject was seated behind a 61 × 20 cm wooden table and viewed the display from a distance of approximately 89 cm. A Biometrics headrest (Model 115) with chin support, mounted on the table in front of the subject, was used to secure the head in the restrained viewing condition. The subjects were seated without restraint in the unrestrained (free viewing) condition. When not in use, the headrest was removed from the experimental chamber.

The walls of the chamber in which the subjects were tested were painted flat white. Ambient illumination was supplied by a light source mounted in a cylindrical ceiling fixture. The luminance reflected from the walls of the chamber, as measured by a Spectra Brightness Spotmeter located at the subject's head, was 4.5 fL. The noise of an exhaust fan served to mask random laboratory sounds. Control equipment and the experimenter were located outside the chamber. An intercom permitted voice communication as well as acoustic surveillance of the subject's activities during the vigil. Subjects surrendered their watches at the start of the session, and they had no knowledge of the length of the session other than that it would not exceed 2 h.

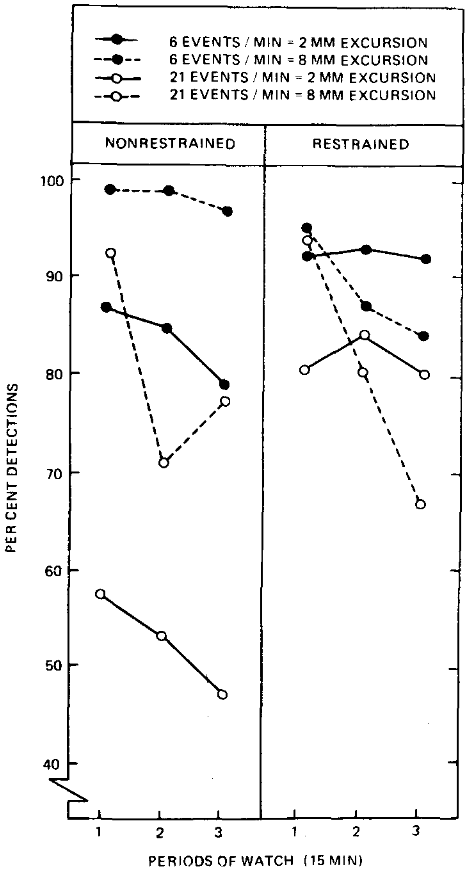

Figure 1. Percentage of signals detected as a function of periods of watch. Critical signal amplitude and background event rate are the parameters. Data for nonrestrained and restrained viewing conditions are presented separately in each panel.

RESULTS

The percentage of correct responses was calculated from the data of each subject for each 15 min period of watch. Mean percentage of correct detections are plotted in Figure 1 as a function of periods of watch with critical signal amplitude and background event rate as the parameters. Data for the nonrestrained and restrained viewing conditions are presented separately in each panel. These means and corresponding standard deviations are given in Table 1.

An analysis of variance of an arcsin transformation of the data revealed that, in general, critical signals of high amplitude were detected more frequently than those of low amplitude, $F(1,112) = 8.06$, $p < .01$, and that the percentage of signal detections was greater under the slow than under the fast event rate, $F(1,112) = 26.54$, $p < .001$. In addition, overall detection efficiency suffered a significant decline as time on watch progressed, $F(2,224) = 9.12$, $p < .001$. Head restraint did not have a significant overall effect on the frequency of detections, $F(1,112) = 3.50$, $p > .05$. However, there were significant single-order interactions between head restraint and signal amplitude, $F(1,112) = 11.34$, $p < .005$, and between head restraint and event rate, $F(1,112) = 4.91$, $p < .05$. There was also a significant single-order interaction between signal amplitude and time on watch, $F(2,224) = 4.14$, $p < .025$, as well as a significant double-order interaction between amplitude, head restraint, and periods of watch $F(2,224) = 3.06$, $p < .05$. All of the remaining sources of variance in the analysis lacked significance.

The interaction between head restraint and event rate is shown in Figure 2. Mean percentages of correct detections are plotted as a function of event rate for nonrestrained and restrained viewing conditions.

The figure clearly indicates that the use of head restraint attenuated the effects associated with variations in event rate. The difference in the percentage of signals detected between the slow and fast event rates is approximately two and a half times smaller under the restrained than under the nonrestrained viewing conditions.

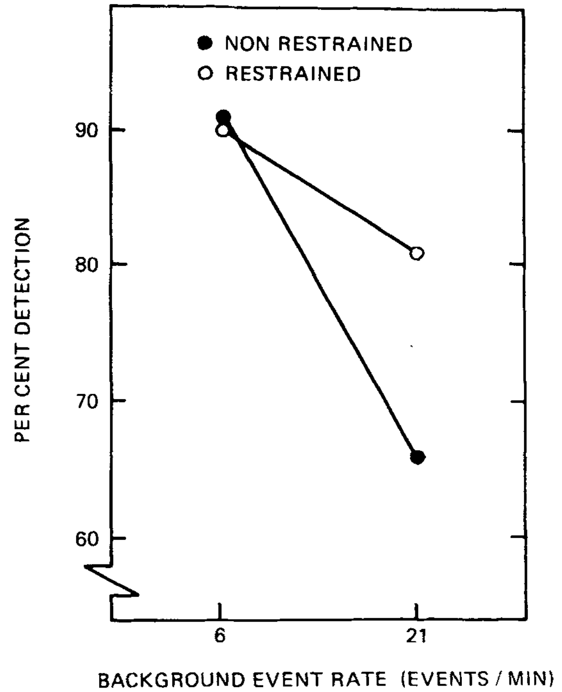

Figure 2. Percentage of signals detected with slow and fast background event rates under nonrestrained and restrained viewing conditions.

The Amplitude by Head Restraint by Periods interaction is presented in Figure 3. Mean percentages of signal detections are plotted as a function of periods for high- and low-amplitude signals. Data for the nonrestrained and restrained viewing conditions are plotted separately in each panel.

Figure 3 reveals that when subjects viewed the display without head restraint, detection efficiency was greater for high-amplitude than for low-amplitude signals and that, with both levels of signal amplitude, the rate of detections declined over time. It is also evident in the figure that the use of head restraint resulted in a considerable improvement in the detection rate for low-amplitude signals. Indeed, the

Table 1
Mean Percentages of Correct Responses and Corresponding Standard Deviations for All Experimental Conditions

Head Restraint	Event Rate (Events/Min)	Critical Signal Amplitude	Periods of Watch* 1 M	1 SD	2 M	2 SD	3 M	3 SD
Nonrestrained	6	2 mm Excursion	87	24	85	19	79	24
		8 mm Excursion	99	5	99	5	97	7
	21	2 mm Excursion	59	23	53	33	47	34
		8 mm Excursion	92	15	71	30	77	28
Restrained	6	2 mm Excursion	92	10	93	12	92	17
		8 mm Excursion	95	12	87	21	84	28
	21	2 mm Excursion	81	18	84	23	80	32
		8 mm Excursion	93	16	80	28	68	32

*15 min

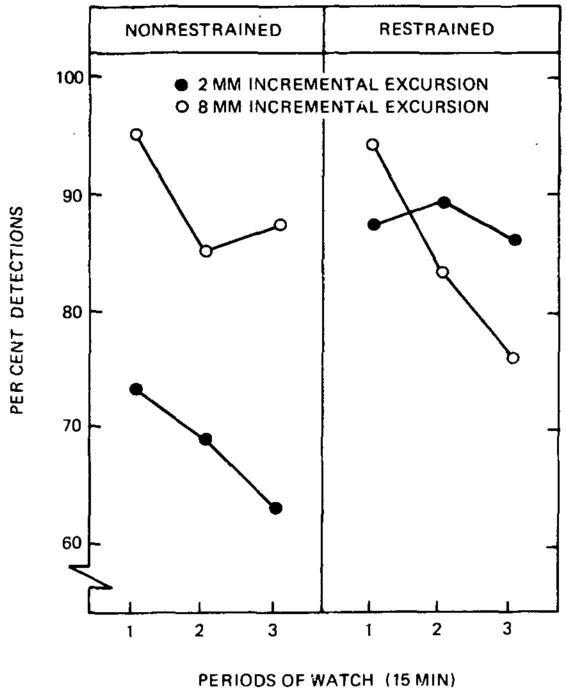

Figure 3. Percentage of signals detected as a function of periods of watch for low- and high-amplitude signals. Data for nonrestrained and restrained viewing conditions are presented separately in each panel.

mean percentage of correct detections for the 2 mm, incremental excursion under restrained viewing (87%) is quite similar to that for the 8-mm incremental excursion under either the restrained (84%) or the free viewing (89%) conditions. Furthermore, when head restraint was employed, the detection rate for low-amplitude signals remained relatively stable across time, while the performance with high amplitude signals declined in a manner similar to that which occurred under the free viewing condition.

The percentage of false alarms was also calculated from the data of each subject for each 15-min period of watch. An analysis of variance of an arcsin transformation of these data revealed that false alarm percentages were greater at low than at high amplitudes, $F(1,112) = 7.02$, $p < .025$, and greater at slow than at fast event rates, $F(1,112) = 5.02$, $p < .05$. The mean percentages of false alarms for low- and high-amplitude signals were 7.2 and 2.9, respectively, while for the slow and fast event rates, the mean percentages of false alarms were 7.4 and 2.6, respectively. In addition, the analysis revealed that the frequency of false alarms decreased significantly over time, $F(2,224) = 23.41$, $p < .001$. The mean percentages of false alarms from the first through the third period of watch were 6.2, 4.9, and 4.0, respectively. Head restraint had no appreciable effect on the frequency of false alarms ($F < 1$), and all of the interactions in the analysis lacked significance, $p > .05$ in each case.

Although a number of investigators (e.g., Broadbent & Gregory, 1963; Loeb & Binford, 1964) have, at the suggestion of Egan, Greenberg, and Schulman (1961), computed signal detection measures for vigilance data, the low percentages of false alarms in the present case make such computations questionable (see Green & Swets, 1974). Moreover, the fact that both hits and false alarms have been found in other experiments to decline within sessions while only false alarms decline from session to session when subjects are tested on successive days suggests that signal detection theory may not provide a simple explanation of vigilance effects (Binford & Loeb, 1966). Accordingly, signal detection theory indicies are not presented here.

DISCUSSION

This investigation has revealed that head restraint does indeed have a positive effect on the detection of signals in a visual monitoring task. In the nonrestrained or free viewing condition, the percentage of signals detected varied directly with critical signal amplitude and inversely with the rate of repetition of neutral events. By contrast, when head restraint was employed, the detectability of low-amplitude signals was enhanced considerably and the difference in the frequency of detections between event rates was attenuated. To our knowledge, these results represent the initial experimental demonstration that the effects of signal amplitude and event rate can be modified by controlling the freedom with which the observer can position himself in viewing the monitored display. They provide additional support for the role of sense mode coupling in visual monitoring performance.

The outcome of this investigation has potentially important implications for a variety of watchkeeping situations in which the observer must scan a dynamic display for changes in regularly occurring stimulus events. Therefore, in terms of the nature of observing activity, it is useful to try and specify the precise manner in which head restraint improved detection efficiency in this case. One obvious possibility is that head restraints was effective because it reduced perturbations in viewing conditions arising during the course of the session with free observing.

More specifically, recall that subjects were looking for occasional increments in the horizontal excursions of a bar of light. When free observing was permitted, head movements may have resulted in signals appearing in peripheral vision. Since motion perception is relatively poor in the periphery (Graham, 1965), this would have made the small, 2-mm, incremental excursions which constituted low-amplitude critical signals particularly hard to see. Head restraint could have led to improvement in the detection of such signals by increasing the likelihood that the display to which the subject had to attend would be in the center of his field of view. Still another way in which head restraint may have been helpful from an observing point of view is in relation to the role of the sight bar mounted on the display. The sight bar marked the end of a neutral excursion and was particularly useful in enhancing the visability of low-amplitude signals. It is conceivable that during free observing, head movements may have resulted in a parallax effect in which the apparent position of the sight bar was altered. In this way, its usefulness as an aid to detecting 2-mm incremental excursions could have been reduced. Holding the head in a fixed position with respect to the sight bar may have minimized parallax changes and thereby enhanced the detectability of low-amplitude signals.

A similar approach can be taken to explain the interaction between event rate and head restraint. It could be argued that a fast event rate—which has been characterized as involving more unreinforced observing responses than a slow event rate (Jerison, 1970)—increases the probability that the head will not be held in the appropriate position to view the display. Thus, with a fast event rate, there will be more signals observed peripherally and greater parallax effects and, hence, fewer detections than with a slow event rate. With the head restrained, the tendency to hold the head in a less than optimum condition will not be as likely to occur and differences in the frequency of detections between event rates will be attenuated.

One of the most ubiquitous features of vigilance tasks is the decrement function, the progressive decline in detections over time. In the present experiment, this effect was linked to the difficulty of the discriminations to be made and to the conditions of observing. As noted previously, the vigilance decrement was observable with both low- and high-amplitude signals under free viewing conditions. With the head restrained, the decrement did not occur for low-amplitude signals, but it continued to be observable in the case of high-amplitude signals. Some investigators have attributed the decrement to an increase in inappropriate observing activities with time on watch (Holland, 1958; Jerison, 1970) and, on the basis of our previous discussion, the absence of a decrement with low-amplitude signals in the presence of head restraint fits easily within this approach. However, the continued observation of a decrement with high-amplitude signals in the presence of head restraint does not.

It is worth noting that several previous investigations have examined the relation between overt observing responses and the vigilance decrement with equivocal results; the temporal course of detections has been associated with systematic changes in observing behavior in some cases (Schroeder & Holland, 1968) but not in others (Baker, 1960; Broadbent, 1963; Guralnick, 1973; Hockey, 1973). It is obvious that the nature of the relation between observing behavior and the vigilance decrement is quite complex and still poorly understood. With respect to the present results, it is possible that during the course of a watch, subjects acquire observing strategies in which they resort to aids to signal detection, such as the sight-bar/head-restraint combination used here, primarily when the discriminations involved are difficult. It is also possible that the gross type of observing or orienting activity that may have been controlled by head restraint in this study contributes to the decrement function only under conditions in which signals have a low value of perspicacity. Both of these possibilities warrant further investigation.

It should also be noted that there are other models of vigilance—e.g., the arousal model (Frankmann & Adams, 1962)—which might also be employed to explain some of the observed effects of restraint. It could be argued, for example, that the extra tactual stimulation provided by the restraint situation produces enough arousal to prevent a decrement due to lowered arousal over time in the relatively challenging situation where the signals are difficult to discriminate. With easier (larger) signals, the situation may be less challenging, and so less arousal and more decrement might occur. Other of the numerous models of vigilance might be invoked as well. It is our view, however, that the observing response hypothesis provides the simplest and most satisfactory model of the restraint effect observed in this investigation.

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