Operant Control of Eye Movements during Human Vigilance

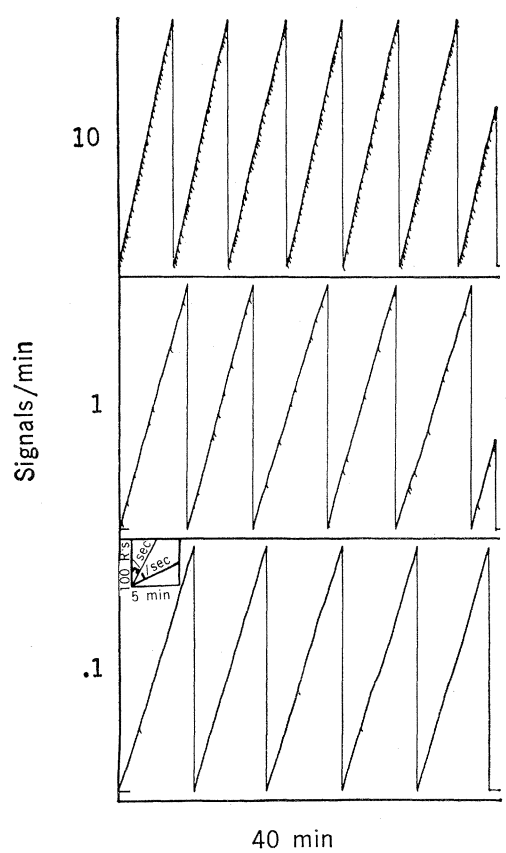
Abstract. *Eye movements were used as a criterion of observing responses in a vigilance task. Time on watch and signal rates similarly affected both eye-movement rates and percentage of detections. Observing rate may account for detection data, and may be a more stable measure of vigilance than detection rate is, especially when very few signals occur.*

Vigilance research is concerned with maintenance of a (human) monitor's efficiency in detecting infrequent changes in stimulus events over prolonged periods of sustained observation. In practice, vigilance is defined in terms of efficiency in performance over periods of a given session, and may be given as percentage of signals detected or missed, detection latency, change in threshold intensity, or some statistical measure dependent upon signal detectability. An alternative approach (*1*, *2*) accounts for the signal-detection data in terms of the frequency of precursory responses (pressing keys which illuminate the display briefly) which bring about detection. Evidence has been adduced that these observing responses may account for much of the vigilance-detection data and are themselves operant responses controlled by signal detections shown to operate as reinforcers. Thus, in vigilance situations where observing increases the probability of detection, vigilance behavior can be examined according to the laws of operant conditioning of observing responses rather than according to some postulated process or state of the organism, as is the more common approach (*3*).

Some investigators have questioned whether this method of analysis holds for other components of observing, such as head orientation (*4*), general bodily activity (*5*), that is, observing responses with more face validity. We therefore performed a conventional vigilance study by varying signal rates and using the Mackworth eye-movement camera (*6*) to assess the function of eye movements in observing behavior. The Mackworth camera uses corneal reflection and a closed-circuit television system. Location of the corneal reflection is automatically digitized so that location, frequency, and duration of eye fixations can be recorded. Research indicates that gross saccadic eye movements are conditionable and behave as specific instrumental responses (*7*).

Our experimental task was analogous to Holland's (*1*, *2*) except that eye movements instead of key-pressing were used as observing responses. Sixteen subjects monitored a four-dial display for pointer deflections. Dials placed in the corners of the display at a distance of 11° (visual angle) from each other required shifts in fixation to monitor the whole display. Four unlit jewel lights and a picture of a sensuous girl were in the center of the display to give subjects something to look at when they became bored. Transient signals (2.5 seconds) occurred during 40-minute sessions. Three different signal rates were used: 10, 1, or 0.1 signals per minute. Each subject experienced six sessions, two consecutive sessions on each signal rate. Order of signal-rate presentation was counterbalanced. A response was a fixation on any one of the four dial areas. A new eye movement was scored only if the subject looked out of a dial area and back into it or into another area. Each dial area was 4° by 4° (visual angle) to compensate for minor shifts in calibration of the corneal reflection. In addition, the experimenter made small adjustments in calibration throughout each session. The subject was credited with detection if he pressed a button within 2.5 seconds after a pointer deflection.

Data from the second session of each signal rate of each subject were used for analysis. All percentage data were arcsin transformed. Results confirm two usual vigilance effects and show appropriate parallels for eye-movement data. (i) As signal rate decreased, percentage of signals detected decreased. Mean percentage of detections per session were 65, 54, and 41 for signal rates of 10, 1, and 0.1 per minute, respectively ($P < .001$, analysis of variance). (ii) Eye-movement rate also decreased as signal rate decreased. Mean eye-movement responses per session were 1044, 811, and 613 for signal rates of 10, 1, and 0.1 per minute ($P < .001$). (iii) For the two higher signal rates the percentage of signals detected significantly



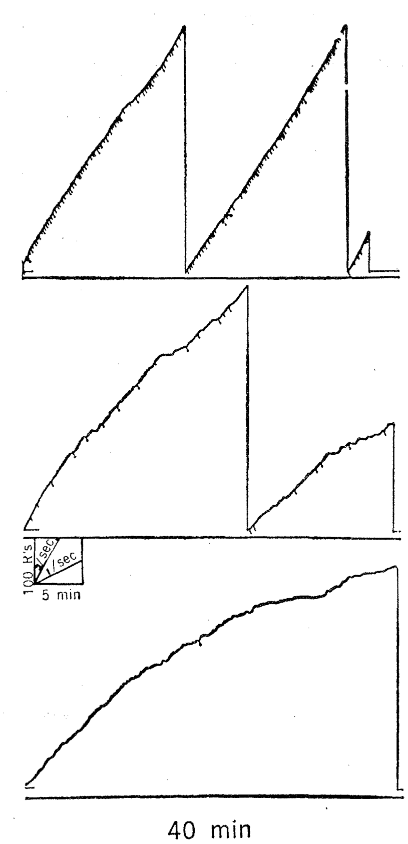


Fig. 1 (left). Cumulative records of eye-movement rates for subject J.S. Distribution of signal intervals was rectangular and ranged from 1 second to double the average interval. Time is on the abscissa. Each response raises one small deflection of the recording pen in the vertical direction. Pips on curves are signal detections. Fig. 2 (right). Cumulative records of eye-movement rates for subject K.S. Distribution of signal intervals was rectangular and ranged from 1 second to double the average interval. Pips on curves are signal detections.

decreased ($P < .01$) with time on watch. The means for successive 10-minute intervals were 69, 65, 64 for the signal rate of ten per minute and 58, 55, 52, 50 for the signal rate of one per minute. The lowest signal rate (0.1 per minute) had only one signal per 10-minute interval for each subject and failed to provide a significant trend through the session. (iv) All three eye-movement rates showed significant decrements ($P < .001$) as sessions progressed. Means for successive 10-minute periods were 988, 957, 890, and 849.

In general, our data conform to traditional effects found for percentage of detections (*8*) and showed parallel eye-movement rates (*9*). The detection efficiency on the slow signal rate is an exception. However, this exception emphasizes the major difficulty with using a response which depends only on the occurrence of a signal. If signal rate is extremely low and few signals are presented, a very large N must be used to obtain stable results, and a high degree of error variance must be tolerated in statistical analyses. In contrast, an observing-response measure can show moment-to-moment fluctuations in monitoring behavior even in the absence of signal presentation (Fig. 1). In addition, observing rates parallel detection rates, suggesting that the observing responses could reflect monitoring efficiency better since they are based on more data.

To evaluate the correspondence of eye-movement rates and percentage of detections, mean eye-movement rate and mean arc-sin percentage detections for each 10-minute period were then correlated. The Pearson r for the two fast rates pooled was .98. The slow signal rate was analyzed separately. Its correlation of detection rate and eye-movement rate was low (.006). The eye-movement rate data and detection data of each individual for 10-minute periods were then correlated. Although a wide spread of values was found ($-.27$ to $+.99$), the majority of the correlations were high (median = .84). Those subjects who showed low correlations had slower and more erratic eye-movement rates and detection rates, or both (Fig. 2). Subjects with high correlations most often had higher and more uniform eye-movement rates (Fig. 1). It thus appears that, as signal rate decreases, response rates become more variable both within and between sessions; consequently, correlational analyses grow less stable and should be interpreted with caution. However, detection rate can be expected to be more susceptible to these inconsistencies since it is based on a much smaller amount of data than eye-movement rate is.

Individuals with higher overall eye-movement rates detected many more signals. Mackworth, Kaplan, and Metlay (*9*) found a similar result on a clock-watching vigilance task. Their interpretation is that speed of shifting of fixation is an index of "alertness."

Subjects sometimes fixate a signal without seeing it, as Baker (*5*) found for a clock-monitoring task, and Mackworth, Kaplan, and Metlay (*9*) found for both a one- or two-clock monitoring task. The same result was confirmed in our study. But, in addition, it was found that rate of looking without reporting was sensitive both to signal rate and time on watch. The slower the signal rate and the longer the time on watch, the greater the tendency to fixate a signal without reporting it. Thus "looking without seeing" seems to follow the same course as detections and eye movements and seems to be controlled by the same variables. This effect might be a function of other more subtle components of the act of observing. In conclusion, our results support Holland's (*2*) suggestion that detection data in vigilance experiments reflect observing responses, be they contrived, like key-pressing to illuminate the display, or more natural, like eye movements.

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Temporal Relation Between Long-Lasting Aftercontractions and Action Potentials in Cat Papillary Muscles

Abstract. *Sotalol, an adrenergic-blocking and antiarrhythmic agent, increases markedly and simultaneously the duration of both action potentials and contractions in papillary muscles. The active tension is manifested as a main twitch contraction followed by a maintained low level of residual tension (aftercontraction) which persists until the terminal phase of rapid repolarization. The strength of the aftercontraction is augmented when the extracellular concentration of calcium is increased.*

Procedures for investigating excitation-contraction coupling in cardiac muscle are still rather limited. We now describe a pharmacological method by which electrical and mechanical events may be varied. Sotalol [(±)-4-(2-isopropylamine-1-hydroxyethyl)methanesulfonanilide HCl], or MJ 1999, is a competitive blocking agent at the adrenergic receptors of the heart (β-receptors) (*1*) and has antiarrhythmic properties (*2*). It also enhances the strength of contraction of cat papillary muscles; this positive inotropic effect occurs even in the presence of (±)propranolol and is, therefore, considered nonadrenergic (*3*). In approximately $10^{-4}M$ sotalol, the increase in developed twitch tension is greatest. Once this maximum tension is attained, the terminal phase of relaxation is slowed and becomes longer with continued exposure to the drug. A small amount of active tension (which we shall call an aftercontraction) persists after each contraction, and may last as long as 5 seconds (*3*). We have found that if a driving stimulus is delivered during such an aftercontraction it does not elicit a twitch, even when the voltage is increased to as much as 20 times the previous threshold. This increase in refractory period suggests that the drug may cause an increase in the duration of the action potential. To test this possibility we have examined