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Vigilance: A Review of the Literature and Applications to Sentry Duty

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Abstract

Vigilance, or sustained attention, involves the ability to maintain focus and remain alert for prolonged periods of time. Problems associated with the ability to sustain attention were first identified in real-world combat situations during World War II, and they continue to abound and evolve as new and different types of situations requiring vigilance arise. This paper provides a review of the vigilance literature that describes the primary psychophysical, task, environmental, pharmacological, and individual factors that impact vigilance performance. The paper also describes how seminal findings from vigilance research apply specifically to the task of sentry duty. The strengths and weaknesses of a human sentry and options to integrate human and automated functions for vigilance tasks are discussed. Finally, techniques that may improve vigilance performance for sentry duty tasks are identified.

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NOMENCLATURE

CCTV	Closed Circuit Television
DARPA	Defense Advanced Research Projects Agency
dB	Decibels
dBA	Decibels Adjusted
DOD	Department of Defense
DOE	Department of Energy
EEG	Electroencephalography
fMRI	Functional Magnetic Resonance Imaging
GPS	Global Positioning System
MDARS	Mobile Detection Assessment and Response System
mg	Milligrams
mm	Millimeters
NORAD	North American Aerospace Defence
NSE	Nuclear Security Enterprise
NTSB	National Transportation Safety Board
PET	Positron Emission Tomography
PVT	Psychomotor Vigilance Task
SNL	Sandia National Laboratories
SPL	Sound Pressure Level
TSD	Theory of Signal Detection

1. INTRODUCTION

1.1 Purpose

The purpose of this paper is to review the literature on human vigilance, with the aim of describing how seminal findings from vigilance research apply to the task of a sentry on watch in a guard tower, scanning both land and water environments for unauthorized access at a perimeter. The ability of human sentries to maintain vigilance is of interest to the Nuclear Security Enterprise (NSE) since guards are commonly posted at NSE site perimeters to detect intruders and protect assets. The intent in this paper is to provide information to support decision makers in determining whether a sentry is most appropriate for the given task or whether some form of automated aid may be needed to optimize performance. In this regard, another purpose of this paper is to review the strengths and weaknesses of a sentry and describe options to integrate human and automated functions for vigilance tasks. A final purpose is to identify techniques that may improve vigilance performance for this specific sentry duty task if that option is selected.

1.2. Sentry Duty

Sentry duty is commonly used throughout the Department of Defense (DOD) and Department of Energy (DOE) at a number of locations, including gates to military bases, aboard ships, along a fence or site perimeter, or in a hangar. Many sentry duty tasks support a security mission designed to prevent sabotage, protect property from damage or theft, prevent access to restricted areas by unauthorized persons, and protect personnel. While the exact tasking differs depending on the sentry's specific mission, the general nature of sentry duty is similar. Whatever type of watch, the sentry is expected to devote full attention to it. The guard or lookout must maintain sufficient attention and scan a visual field for long periods of time in order to detect infrequent events—it is not uncommon for sentries to perform lengthy six-hour watches for weeks at a time without detecting a significant signal. In addition to detecting the rare potential threat, sentries may be required to further discriminate friends from enemies, and they may be equipped with weapons so they can function as part of the response to an identified threat. For those types of sentries, accurate marksmanship is as critical as sustained attention.

Sentry duty is a critical task, but even in the 21st century, it is not sophisticated. Sentries rely primarily on their eyes and ears to detect potential threats. Shipboard sentries may be able to use radar to supplement their basic senses, but other sentries, such as those standing watch over site perimeters, may have nothing more than binoculars and radio communications. The perimeter itself may have sensors that will trigger an alarm if a potential intrusion is detected, but the sensor information does not directly support the sentry. The alarm is relayed to a control station in a remote location, and the operators there may use radio communications to convey a possible intrusion for the sentry to investigate further.

Sentries continue to be necessary because there are some situations where technology provides a poor substitute for human capabilities. For example, there are some objects that are impossible or very difficult to detect with radar—smoke, flares, swimmers, torpedo wakes, debris, low-flying aircraft, and life rafts. Sometimes, radar also falsely indicates the presence of objects. Only a human on watch can verify the validity of a radar contact report and identify the objects detected. Further, during periods of technology failure or conditions of electronic silence, lookouts represent the only means of detection. In the case of perimeter sentry duty, it can be advantageous to have a human in the guard tower at the front line with a clear line of sight to the perimeter and the ability to directly perceive the sights and sounds of potential intrusions.

1.3. Vigilance Background

Vigilance, or sustained attention, refers to the ability of observers to maintain their focus of awareness and remain alert to stimuli in the environment over prolonged periods of time (Davies & Parasuraman, 1982). It can be described as a state of readiness on the part of the observer to detect and respond to certain specified small changes occurring at random time intervals in the environment (Mackworth, 1957). Thus, vigilance tasks, also called monitoring or watchkeeping tasks, involve the direction of attention to one or more sources of information over long, unbroken periods of time, for the purpose of detecting small changes in the information being presented (Davies & Parasuraman, 1982). The source of information is often, but not always, some type of intermediate display (e.g., radar, sonar, pressure gauge) to which the observer must attend. As in the case of a sentry on watch in a guard tower, however, vigilance may occur in the natural environment with no intervening display. All monitoring activities encompass the functions of detection or receipt of information, decision making with respect to the interpretation and integration of sensory inputs, and responses appropriate to the decisions, regardless of whether a display is involved.

1.3.1. Historical Background

The study of vigilance had its beginnings in World War II when it was discovered that British radar observers on antisubmarine patrol over the Bay of Biscay failed with increasing frequency to notice the blips of light that indicated the presence of enemy submarines below. This decline in accuracy over time was particularly troubling not only because of its potential consequences but also because it occurred in the presence of an apparently high level of motivation on the part of the British pilots. As a result, the Royal Air Force commissioned Norman Mackworth to study the problem in an effort to determine why the change in performance was taking place.

Mackworth (1950) thus began the first systematic laboratory research on sustained attention by using a simulated radar display called the clock test. The display consisted of a blank clock with no reference points or scale markings on it. Once every second a black pointer moved .3 inch along the circumference of the clock. Occasionally, it moved .6 inch instead of the usual .3 inch. This double jump of the pointer constituted the critical signal or target to be detected. During a two-hour session, subjects were required to press a key whenever they saw the double jump. In this way, Mackworth was able to observe the nature of the decline in performance over time while controlling for the effects of extraneous and confounding variables. The number of correct detections declined sharply from the first to the second half-hour and then declined more gradually for the remainder of the session. This decrement function, or *vigilance decrement*, continues to be the most pervasive finding in vigilance research. The decline in performance is typically complete 20 to 35 minutes into the session, and at least half of the final loss is completed within the first 15 minutes (Teichner, 1974). As Dember and Warm (1979) have noted, the most striking aspect of this finding is that it seems to stem simply from the need to look or listen for a relatively infrequent signal over a continuous period of time. Typical vigilance decrement curves are illustrated in Figure 1.

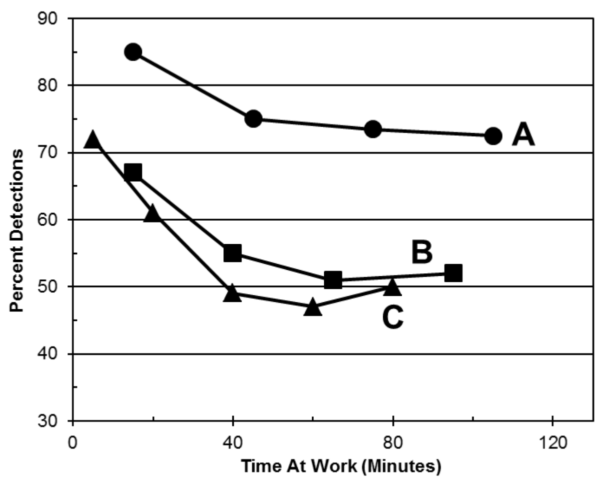

Figure adapted from Jerison and Pickett (1963)

Figure 1. Three Typical Vigilance Decrement Curves.

The characteristics of Mackworth's initial task, based largely on the demands associated with real-world radar monitoring and detection, have come to be considered the cardinal elements of vigilance situations. These features are typically employed in laboratory studies of vigilance. The first feature is a prolonged and continuous task with a duration of at least 30 minutes. Second, the signals to be detected are relatively weak, but they are clearly able to be perceived when observers are alerted to them. Third, the signals occur infrequently and without warning. Fourth, the responses of observers do not affect the appearance or probability of signals in any way.

Performance for vigilance tasks may be characterized in terms of speed and accuracy. Speed represents the latency in responding to critical signals for detection and is typically measured in milliseconds or seconds. The most common accuracy measures include correct detections of critical signals or targets (also termed hits) and false alarms (incorrect designations of nonsignal events as targets). These measures are generally expressed as percentages. Performance accuracy during a vigil may also be expressed in terms of the theory of signal detection (TSD). TSD is a model of perceptual processing that provides a measure of the observer's perceptual ability (referred to as sensitivity, or the ability to differentiate targets from nontargets) and an independent measure of the observer's willingness to make a target response (referred to as response bias). TSD measures of sensitivity and response bias are derived from observers' hits and false alarms. The parametric and nonparametric measures of sensitivity and response bias that may be reported in vigilance studies are identified in Table 1.

Table 1. TSD Measures of Vigilance Performance

Model[1]	Index	Measures	Values	Description
Parametric	Sensitivity	d'	< 1.5 1.5 – 2.5 2.5 – 3.5 > 3.5	Very Difficult Moderately Difficult Moderately Easy Very Easy
	Response Bias	β	1.0 0 – 1.0 > 1.0	Neutral Lenient Conservative
		c	0 < 0 > 0	Neutral Lenient Conservative
Nonparametric	Sensitivity	A'	.5 up to 1.0	Chance Performance Perfect Performance
	Response Bias	B''	0	Neutral
		B'_H	-1 to < 0	Lenient
		B''_D	> 0 to +1	Conservative

[1]Parametric model: assumptions of normality and variance in the underlying data are met
Nonparametric model: assumptions of normality and variance may not be valid

1.3.2. Vigilance in the Real World

The signal detection problems of World War II that prompted vigilance research persist in multiple real-world military and civilian situations today (Table 2). Watchkeeping in surveillance missions, sentry duty, and target acquisition in armored combat are all military activities that involve monitoring functions. Observers on sentry duty, for example, must remain alert for critical signals such as sights and sounds that indicate potential intrusion attempts at a security perimeter. Similarly, armor crews must sustain attention in order to detect targets such as gun flashes and enemy vehicles under conditions of heat, noise, and prolonged work shifts, all of which can degrade the quality of sustained attention (Warm, 1993). Lapses in attention on the battlefield caused by these and other factors can have dire consequences, including injury, loss of life, and security breaches.

Table 2. Real-World Vigilance Issues

Year	Vigilance Shortfall
1945	British airborne observers on patrol over the Bay of Biscay miss "blips" on their pulse-position radar displays representing German U-boats in the sea below, leaving the Allied forces **vulnerable to enemy attack**.
1988	Aloha B-737 aircraft suffers **fuselage failure** after quality control inspectors fail to detect multi-site damage.
1991	Technicians at a switching center in Manhattan fail to notice visual and auditory alarms warning of trouble that eventually led to telephone failure and disruption of air traffic control. Three airports were virtually closed; nationwide, more than **200 flights were delayed.**
2003	A British Royal Air Force Tornado returning from Iraq is **shot down** by a U.S. Patriot missile defense battery, in part because the highly automated Patriot missile system's display was cluttered with false or spurious tracks that exacerbated operator detection.
2006	Baggage screeners at Newark Liberty International Airport fail 20 of 22 security tests conducted by undercover agents, **missing bombs and guns at checkpoints** concealed under bottles of water in carry-on luggage, taped underneath an agent's clothing, and hidden under a leg bandage.
2009	Northwest Airlines pilots **overshoot their destination** by 150 miles after failing to notice numerous warnings from cockpit displays and air traffic controllers.
2010	At Boston's Massachusetts General Hospital, a **heart patient dies** as a result of "alarm fatigue"—for 20 minutes, nursing staff "tuned out" various alarms that indicated the patient's heart rate fell and finally stopped.
2012	Three protesters **breach the security perimeter and cause $70,000 in damage** at a storage site for enriched uranium in Oak Ridge, Tennessee. Despite triggering alarms in the central system where security guards keep watch, the breach is not detected for over two hours.
2013	Asiana Airlines Flight 214 **crash lands** in San Francisco, **killing three and injuring nearly 200**. Four pilots on board fail to notice the plane is flying slower than the recommended landing speed until seven seconds before impact.

In addition to the military applications, vigilance is also required in many civilian tasks, more so now than in the past in light of the changing role of the human operator. The growing use of automation and computerization in industry and aviation has led to the shift from active, manual control to supervisory control (Sheridan, 1970). Employees today must rely less on physical skills and more on their mental abilities as they encounter tasks that require them to monitor dials, video screens, and other displays for signs of malfunction or danger that demand rapid decision making and action. Activities requiring vigilant behavior include industrial quality control, robotic manufacturing, air traffic control, airport screening and inspection, nuclear power plant operations, long distance driving, transport operations, seaboard navigation, cytological screening, closed circuit television (CCTV) surveillance, and the monitoring of medical equipment in hospital settings (Beatty, Ahern, & Katz, 1977; Davies & Parasuraman, 1982; Mackie, 1977; Wiener, 1984). The maintenance of vigilant behavior is crucial not only for worker efficiency and safety but also for the security of the general public.

1.3.3. Validity and Generalizability of Laboratory Studies of Vigilance

Laboratory studies of vigilance began as a result of an identified real-world problem. As evidenced in Table 2, real-world vigilance concerns continue to occur. One question that has plagued vigilance research almost from the beginning is how well the results of carefully controlled laboratory studies actually apply to real-world vigilance tasks. To be sure, there have been criticisms in this regard (Adams, 1987; Kibler, 1965; Morgan, 1980; Teichner, 1974). However, there is a general belief that vigilance research is relevant and applicable to the performance required in real-world monitoring and inspection tasks (Morgan, 1980; Parasuraman, Warm, & Dember, 1987). Industrial inspection tasks are frequently included in the vigilance literature since inspectors may need to sustain attention for long periods of time as they inspect multiple items. Thus, conclusions regarding the generalizability of inspection research may well hold true for the field of vigilance. In that regard, a review of research findings in inspection indicated that results associated with task factors (e.g., defect rate, defect type, and product complexity) generalize well to real-world industrial applications (Drury & Wang, 1986).

While this result is encouraging, vigilance researchers recognize that there is an ongoing need to verify whether laboratory studies continue to represent and apply to evolving real-world tasks. Laboratory studies that were valid for real-world tasks common in the 1980s may not necessarily be entirely relevant for situations encountered in 2014 and beyond. Traditional laboratory studies of vigilance have frequently designed tasks to simulate the weak, brief duration signals that were commonly encountered during the World War II era. Technology has improved vastly since then, and the nebulous signals common to radar displays at that time are rarely encountered in today's monitoring tasks. Traditional laboratory vigilance studies have generally used simple static displays with uncluttered backgrounds and one-dimensional signals like alphanumeric characters, lines, and simple geometric shapes. Frequently, the observer has been required to monitor only one source of information for a single target type, with stimuli presented in discrete sequential trials. These types of traditional displays bear little resemblance to many modern day vigilance tasks in which information is presented dynamically in the context of complex backgrounds that may contain many different types of targets for detection (e.g., airport baggage screening). Finally, traditional laboratory vigilance studies have usually required an observer to respond only if a target is detected (usually by pressing a designated key on a standard keyboard). Real-world vigilance tasks often require more than a simple detection response. For example, baggage screeners who detect a weapon must do more than simply acknowledge the presence of the threat.

1.3.3.1. Modern Studies of Vigilance

To enhance the overall generalizability of laboratory results, Wiener (1987) urged researchers to study vigilance in more complex and operationally valid environments. In accordance with recommendations like this, vigilance research is continually being adapted to ensure that it reflects real-world applications. To date, no significant departures from the findings based on traditional laboratory experiments have been observed when studies use more complex and realistic displays.

NORAD Study. Pigeau, Angus, O'Neill, and Mack (1995) conducted a vigilance study using the real-world North American Aerospace Defence (NORAD) task for identifying aircraft entering Canadian airspace. The researchers used NORAD's live air picture for their study, but they injected simulated tracks that looked exactly like genuine tracks in order to reliably assess detection performance. This approach permitted an evaluation of vigilance performance in realistic operational conditions, but with some degree of the experimental control characteristic of laboratory studies. Although there was no overall main effect for time on task, a vigilance decrement did occur for operators working the midnight shift (12:00 a.m. to 7:00 a.m.). This result is entirely consistent with previous studies of vigilance using simpler displays in laboratory settings.

CCTV Study. Donald and Donald (2011) examined how CCTV operators manage attention in order to cope with the vigilance demands of the task. Forty-two real-world CCTV operators performed a 90-minute video surveillance task in order to detect four target behaviors (e.g., picking up a small object or kicking an object to another location). All of the video was shot in diamond processing plants and represented realistic work activities. Operators demonstrated alternating periods of engagement and disengagement throughout the 90-minute task. Approximately 23% lost concentration in the first 30 minutes, 60% in the second 30 minutes, and 50% in the last 30 minutes. The researchers concluded that the need for operators to take "time-outs" indicated difficulty in sustaining attention and maintaining concentration on the task.

Natural Scene Stimuli Study. Head and Helton (2012) conducted two vigilance experiments using naturalistic forest or urban scene stimuli instead of the more simple targets of traditional studies. A vigilance decrement occurred, despite the use of non-repetitive, natural target stimuli—correct detections declined and reaction time increased significantly over time. This study provides evidence that the use of simple stimuli in laboratory vigilance tasks may not necessarily impair generalizability. The authors concluded that a vigilance decrement can occur in any detection task requiring continuous target/nontarget discriminations, even if the stimuli consist of complex natural scenes that are more representative of real-world stimuli.

Maritime Watch. To investigate vigilance performance during a typical maritime watch, Van Leeuwen *et al.* (2013) conducted an eight-day study in a realistic bridge simulator. The simulator consisted of large plasma screens for visualization and genuine bridge instrumentation, including global positioning systems (GPS), radar, autopilot, radio, and intercoms. Thirty bridge officers performed watch duties in accordance with the schedule typically followed in maritime watch—two shifts per 24-hour period consisting of 4 hours on duty and 8 hours off duty. The voyage used in the study was based on recordings of normal traffic in the North Sea and English Channel to closely represent real-world maritime traffic. Bridge officers completed a vigilance task at the beginning and end of every 4-hour watch period. Vigilance decrements occurred in all watch periods, as evidenced by slower reaction times and more lapses in attention at the end of a watch as compared to the beginning.

1.3.3.2. Applications to Sentry Duty

With respect to sentry duty tasks, findings from the vigilance literature are directly applicable since studies that have focused exclusively on vigilance for sentry duty form part of the body of literature that is reviewed in this paper. Studies of the impacts of vigilance on detection, discrimination, and marksmanship performance during sentry duty began in the 1980s and continue to the present. Sentry duty vigilance studies have been conducted primarily at the U.S. Army Research Institute of Environmental Medicine and the Walter Reed Army Institute of Research. Data are collected during both realistic simulator sessions and live fire field studies, using active duty soldiers. The simulators use modified real-world rifles that incorporate realistic recoil and auditory feedback. Performance on the rifle simulator has been shown to predict actual live fire performance on the rifle range and is therefore viewed as equivalent to a live fire test. The simulator affords the realism of the field but can be used in a laboratory environment that permits control of extraneous and confounding variables, as in Mackworth's initial clock test.

Sentry duty also bears many similarities to CCTV, and these studies also form part of the literature reviewed in this paper. CCTV surveillance operators are responsible for protecting people and property in a range of settings, including critical infrastructure (e.g., airports, train stations, ports, and government buildings) and public spaces (e.g., shopping malls and streets). CCTV surveillance is vigilance intensive—operators are required to sustain attention for long periods of time and maintain high levels of concentration in order to detect incident conditions or deviations from standards. Operators typically observe 3 to 30 camera scenes concurrently to detect potential incidents, interpret the information, and respond to it. The tasks of sentries and CCTV operators map directly—the primary difference is the fact that sentries may monitor the natural environment, whereas CCTV operators monitor displays.

In general, the results of sentry duty and CCTV studies do not differ from traditional studies of vigilance using configurations similar to those in Mackworth's original studies. In fact, the intervals of time between targets that are used in many of the sentry duty studies exactly duplicate those from Mackworth's initial clock studies. Further, as noted by Johnson and McMenemy (1989), although Mackworth's task was specifically modeled after a radar operator, it is analogous to that of a soldier on sentry duty because the fundamental mechanisms needed to sustain attention and perform the tasks are the same. Like the radar operator, the soldier on sentry duty must scan a visual field and detect the appearance of enemy targets for prolonged periods of time.

1.3.3.3. Theories of Vigilance

According to Jerison and Pickett (1963), an adequate theory of vigilance is necessary for addressing the question of the applicability of laboratory data to field situations. Theory provides a foundation for guiding research and for designing research that will apply to real-world issues. A dozen major theories have been proposed and investigated in an attempt to account for the vigilance decrement and the overall level of performance achieved during a vigil. To date, no single theory has yet provided a completely satisfactory explanation of the vigilance data, although each has some amount of explanatory power. At present, resource theory has received the broadest support from vigilance research (Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975; Wickens, 1984).

Resource theory views attention as a flexible, sharable, processing resource with limited availability that enables the performance of a task. Resources are scarce commodities allocated by the perceptual system to cope with the tasks that confront it. The amount of resources devoted to a task varies directly with the immediate demands of the task. Performance efficiency remains stable if processing resources can be expanded to meet increased task demands. However, when the demands of the task exceed the ability of the processing system to expand resources sufficiently, performance on the task will decline.

The current time-dependent view of resource theory holds that task demands consume processing resources over time and that resources are not restored as rapidly as they are used. As a result, the quality of performance will deteriorate over time. Such a proposition has the advantage of being able to explain effectively the decrement that typically occurs during vigilance tasks, which tend to be highly demanding. Indeed, requiring observers to sustain attention for prolonged periods of time is both mentally demanding and stressful, and observers must use their limited information processing resources in order to meet the task demands. As the watch progresses, they have fewer resources left to meet those demands since the replenishment of resources cannot keep pace with the rate at which they are used.

The resource theory of vigilance has broad explanatory value, and it does account for most of the psychophysical determinants of vigilance performance that will be described in this review. One troubling aspect for resource theory is the ambiguity regarding the underlying physiological basis of the attentional resources. There is, however, a growing body of neuropsychological evidence that provides support for the concept of attentional resources. Specifically, positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies suggest that attentional resources may be represented by changes in cerebral blood flow in the frontal cortex. Studies using less restrictive measures of cerebral blood flow and oxygenation have provided similar results, and metabolic changes in cerebral tissue have been shown to correspond to the vigilance decrement.

1.4. Scope

The remainder of this report reviews principal findings from the literature to describe the factors that impact vigilance performance. These include psychophysical, task, environmental, pharmacological, and individual factors. In addition, throughout the document, the significance of research findings specifically for sentry duty tasks is highlighted. Options for human-system integration for vigilance tasks and techniques for improving vigilance performance are also covered.

The majority of the documents included in this review are from the author’s personal library, accumulated as part of her master’s and doctoral research in the field of vigilance. More recent research conducted in the past 10 to 15 years was located by using the keywords *vigilance*, *sustained attention*, and *sentry duty* in Google Scholar. The overall body of research in this review paper includes traditional laboratory experiments designed specifically to explore one or more parameters impacting vigilance performance in a controlled setting; investigations from the security literature examining airport baggage screening, CCTV surveillance, and sentry duty performance; and field studies evaluating performance during real-world vigilance tasks. For some topics, relevant research from the domain of visual inspection is also referenced.

2. PSYCHOPHYSICAL PARAMETERS

The psychophysics of vigilance involves specifying the stimulus characteristics that influence performance. Psychophysical determinants of vigilance performance include the sensory modality of signals, the signal conspicuity or salience, stimulus uncertainty, the characteristics of the background events, and stimulus complexity (Jerison, 1959; Warm & Berch, 1985). Sensory modality, signal salience, nature of the background events, and stimulus complexity have been termed first-order factors because they involve immediate physical properties of the stimulus. Stimulus uncertainty is referred to as a second-order factor because it is a feature of the signal that the observer infers after experiencing the task for a period of time.

2.1. Sensory Modality

The first important characteristic of the task is the sensory modality in which the stimuli are delivered to the observer. Acoustic, tactual, and visual stimuli have all been studied. Although the vigilance decrement is present in all three modalities, it assumes different forms. It has typically been found that auditory tasks result in a higher level of overall efficiency as well as greater stability over time (Davies & Parasuraman, 1982; Warm & Jerison, 1984). The decrement function is not as steep when acoustic stimuli are involved, and both the speed and accuracy of signal detections tend to be higher for auditory signals than for either visual or tactual signals.

Furthermore, intersensory correlations tend to be low or nonsignificant, although it was discovered that audiovisual correlations could be increased by closely coupling observers to visual displays and by equating the types of discriminations required in the two modalities (Hatfield & Loeb, 1968). Coupling prevents observers from looking away from the visual display, making it more similar to an auditory display where subjects are directly linked to the source of stimulation. In addition, equating the tasks in terms of the difficulty of discriminations tends to increase the size of the correlation. It has also been found that experience in one sensory modality transfers to later performance in another modality (Gunn & Loeb, 1967; Tyler, Waag, & Halcomb, 1972).

Performance with redundant displays in which signals are presented both visually and auditorially has also been shown to be superior to single-mode performance (Craig, Colquhoun, & Corcoran, 1976). Observers who receive both visual and auditory information perform more efficiently than those who receive information in only a single modality, as evidenced by more correct detections in the combined condition than in either single-mode condition (Table 3). This dual-mode superiority has been shown to stem from the integration of the two sensory systems and not from a chance combination of their independent activities.

Table 3. Auditory and Visual Vigilance Performance

Measure	Auditory	Visual	Auditory + Visual
Percent Detections	53.4	40.5	60.0
Percent False Alarms	4.5	5.2	5.2
Sensitivity d′	1.8	1.4	2.0
Response Bias β	4.7	3.8	4.1
Reaction Time (seconds)	.8	.8	.7

Table adapted from Craig, Colquhoun, and Corcoran (1976)

The conclusion that has been derived from studies of the role of sensory modality is that modality does exert an influence on vigilance performance but that common factors are indeed present in vigilance performance in different sensory channels. Sustained attention seems to be a general characteristic of the observer, controlled by similar laws of performance in all sensory channels rather than a modality-specific property requiring different laws for different modalities.

2.1.1. Applications to Sentry Duty

The finding that receipt of both visual and auditory information results in more efficient vigilance performance has implications for sentries on watch. Namely, superior performance would be expected if both the sights and sounds of a potential intruder are detectable. Thus, any actions that can be taken to enhance visual and auditory sensory inputs for the observer on watch may be beneficial; for example, gravel will generate more auditory input than grass if an intruder attempts to breach the perimeter.

2.2. Signal Conspicuity

Another first-order factor that influences performance efficiency is signal conspicuity. It has typically been found that signal detection is positively related to both stimulus amplitude and duration. Increasing the amplitude or signal-to-noise ratio of critical signals enhances the overall efficiency of sustained attention and may render performance more stable over time (Loeb & Binford, 1963; See, Warm, Dember, & Howe, 1997). Figure 2 shows results from See *et al.'s* (1997) study for correct detections over time in conditions of low and high signal salience for visual stimuli. In Loeb and Binford's (1963) study, subjects listened for increments in the loudness of repetitive pulses of auditory stimuli. Critical signals were either 2.1, 3.6, or 5.1 decibels (dB) louder than the neutral background events. The number of missed signals decreased as critical signal intensity increased. In addition, the decrement was more stable over time at the higher intensities. Simply increasing the amplitude of the signals increased overall efficiency and reduced the decrement as well.

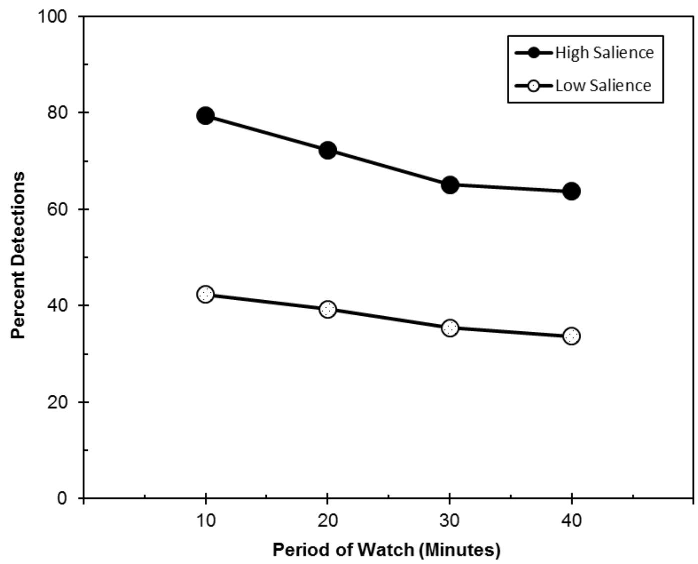

Figure adapted from See, Warm, Dember, and Howe (1997)

Figure 2. Vigilance Performance is More Accurate at High Signal Salience.

In fact, the usual decrement function can even be reversed by "turning up the gain," as demonstrated by Corcoran, Mullin, Rainey, and Frith (1977). These investigators found that abruptly increasing the amplitude of auditory stimuli midway through the vigil increased the frequency of correct detections during the remainder of the session. Thus, one way to enhance vigilance performance may be simply to increase stimulus amplitude at some point later in the vigil. See (1992) extended this finding to the visual modality and demonstrated that simply increasing the salience of the critical signal for detection midway through a vigil may be sufficient to reverse the vigilance decrement.

Stimuli may further be made more conspicuous by increasing their duration. Brief signals are more likely to be missed than signals that remain visible or audible for longer durations (Warm, Loeb, & Alluisi, 1970). As shown in Figure 3, correct detections in the Warm *et al.* (1970) study were less than 25% when signal duration was only .5 seconds. Correct detections increased as the signal duration increased, approaching 100% at durations of 4.0 and 8.0 seconds. No additional benefits for correct detections were observed once the duration reached 4.0 seconds. Thus, detection efficiency can be described as a negatively accelerated increasing function of stimulus duration up to a limit of about 4.0 seconds.

Results associated with signal conspicuity conform quite well to a resource theory for vigilance—more resources will be required to attend repeatedly to very weak or very brief signals. As a result, fewer and fewer resources will be available as the watch progresses, leading to a more pronounced vigilance decrement for low salience signals.

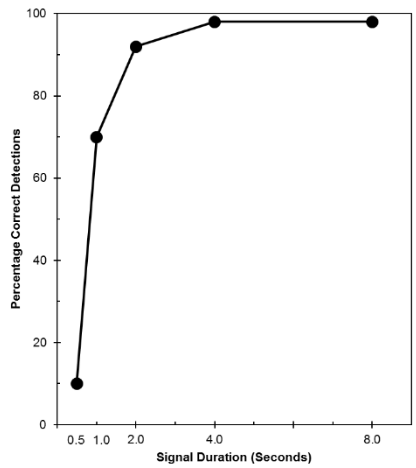

Figure adapted from Warm, Loeb, and Alluisi (1970)

Figure 3. Correct Detections Increase as Signal Duration Increases.

2.2.1. Applications to Sentry Duty

In terms of the sentry on watch, performance might be improved by implementing tactics that delay potential intrusions and make them visible or audible for longer durations.

2.3. Stimulus Uncertainty

Yet another determinant of vigilance performance is stimulus uncertainty, which may take the form of temporal or spatial uncertainty. Temporal uncertainty arises from not knowing when the critical signals or targets will occur, whereas spatial uncertainty involves not knowing where in the display or field of view the signals will appear.

2.3.1. Temporal Uncertainty

Temporal uncertainty may occur in one of two ways. First, uncertainty may be achieved if the density or number of critical signals varies (signal probability). Second, the intervals of time between critical signals for detection may be regular and predictable or irregular and unpredictable.

2.3.1.1. Signal Probability

Studies of signal probability during a vigil indicate that the accuracy of signal detections changes directly as a function of signal density (See, Warm, Dember, & Howe, 1997; Singh, Tiwari, & Singh, 2007; Warm & Jerison, 1984). When signals occur more frequently (i.e. when the signal probability or density is higher), the uncertainty of observers as to when signals will occur is lower; hence, they correctly detect more signals (Figure 4). Critical signal density can also influence the speed with which signals are detected. Response time increases as a linear function of temporal uncertainty (Singh, Tiwari, & Singh, 2007; Smith, Warm, & Alluisi, 1966). Furthermore, the effects of signal probability can persist long after the conditions in which they were initially encountered. Namely, observers trained under conditions of high signal probability subsequently perform more efficiently than subjects trained under conditions of low probability, regardless of the signal density of the subsequent task (Colquhoun & Baddeley, 1964; Krulewitz & Warm, 1977).

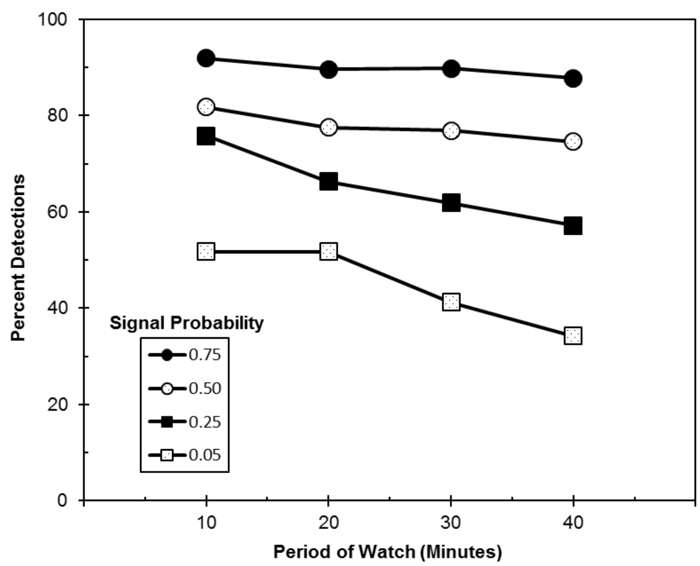

Figure adapted from See, Warm, Dember, & Howe (1997)

Figure 4. Observers Detect More Signals As Signal Probability Increases.

Based on findings regarding the benefits of increased signal probability, one line of research has explored the impacts of a technique called *signal injection*, whereby artificial targets that are perceptually identical to genuine targets for detection are inserted into a scenario (Donald, 2012; Donald & Donald, 2008; Mackie, Wylie, & Smith, 1994). Mackie *et al.* (1994) investigated the effects of signal injection during a four-hour simulated sonar watchstanding task, which is characterized by extremely low signal rates in the real world. Results indicated that detection times were significantly reduced when signal injection occurred, even with very low signal rates of one per hour during the four-hour watch. In a longer experiment in which operators performed four-hour watches over four consecutive nights, with a signal rate of four per hour, no vigilance decrement occurred in the signal injection condition. By comparison, the control group exhibited a performance decrement from the first 15 minutes of the first hour to the first 15 minutes of the fourth hour.

Donald (2012) applied a similar approach to CCTV surveillance, adopting the term *threat image projection* from X-ray baggage screening in aviation. As with signal injection, threat image projection involves electronic insertion of an artificial target into real-time images. Donald (2012) had 73 participants observe a 90-minute CCTV video from an industrial plant, showing both normal work activity and significant events (targets). There were indications that the threat image projections had positive effects on alertness and attention, although the results were not statistically significant. The absence of a robust effect may have stemmed from difficulties associated with accurately depicting key behaviors for dynamic artificial targets, as opposed to the static targets for X-ray baggage screening.

2.3.1.2. Time Intervals Between Signals

The second method by which temporal uncertainty can occur involves regularity of the intervals of time between critical signals. For example, signals may appear on a regular schedule, exactly once every 60 seconds, or signal occurrences may be more unpredictable, ranging from 45 seconds to 5 minutes or more. When signals occur regularly, both the accuracy and speed of signal detections are enhanced as compared to the irregular intersignal intervals (Adams & Boulter, 1964; Warm, Epps, & Ferguson, 1974).

2.3.2. Spatial Uncertainty

Uncertainty during a vigil may also take the form of spatial uncertainty, which can be achieved by varying the probability that signals will appear in different areas of a display/field of view or by using an unpredictable sequence of locations. Spatial uncertainty reduces performance efficiency and causes observers to bias their attention toward those areas of the display where the probability of signal occurrence is the greatest (Adams & Boulter, 1964; Milosevic, 1974; Nicely & Miller, 1957).

2.3.3. Applications to Sentry Duty

Both temporal and spatial uncertainty may be expected for the observer on watch during sentry duty—potential intrusions may occur anywhere at any time. Results from the literature suggest that training for sentries should be conducted at a high signal probability to improve subsequent task performance. During a watch period, it may be beneficial to periodically inject artificial targets in order to increase the signal probability. Further, the potential for attentional bias cannot be ignored for observers on guard duty attempting to detect potential intrusions at a security perimeter—observers will likely focus their attention on those areas of the perimeter that have seen the most attempted intrusions or that have known vulnerabilities. Therefore, if target injection techniques are used, care should be taken to distribute the targets spatially at the perimeter and temporally throughout the period of watch.

2.4. Background Events

The background event context is a further factor that influences vigilance performance, one that has come to be known as the prepotent psychophysical factor in vigilance performance (Parasuraman, Warm, & Dember, 1987). The background events consist of repetitively presented stimuli within which the critical signals to be detected are embedded. The background events are neutral in that they require no response from the observer, but they are far from neutral in their effects on the quality of sustained attention. The background event rate, or the frequency of occurrence of the background events, influences both the speed and accuracy of signal detections. Reaction time increases and accuracy declines as the event rate increases, and the decrement function becomes more pronounced (Jerison & Pickett, 1964; Parasuraman & Davies, 1976; Singh, Tiwari, & Singh, 2007). These effects are illustrated in Figure 5 for correct detections.

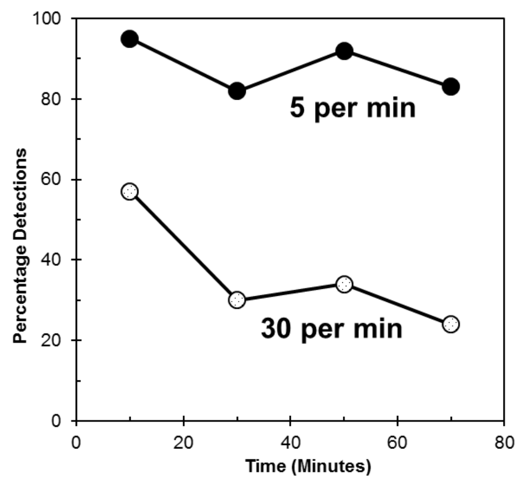

Figure adapted from Jerison and Pickett (1964)

Figure 5. Correct Detections Decrease as the Event Rate Increases.

Furthermore, the quality of sustained attention declines as event rate increases, even when signal density is adjusted so that the probability is equated within event rates (Loeb & Binford, 1968; Parasuraman, 1979). That is, observers might perform better on low event rate tasks versus high event rate tasks, simply because the signal probability will be higher in the task containing fewer events overall if the same *number* of signals is presented in both tasks. As described in the section on stimulus uncertainty, better performance is associated with higher signal probabilities. The event rate effect, however, persists even if the signal probabilities are equal, indicating that the effect is due to more than just the impacts of signal probability.

The background event rate also has the capacity to influence the effects associated with other stimulus parameters. The effects of signal amplitude and signal regularity as well as the enduring effects of signal probability depend on the background event rate (Krulewitz & Warm, 1977; Metzger, Warm, & Senter, 1974; Moore & Gross, 1973). As Moore and Gross discovered, for instance, the benefits of intersignal regularity appeared late in the vigil under a slow event rate and early in the watch under a fast event rate. It appears that the ability to correctly detect critical signals is greatly influenced by what occurs in the interim between signals.

An additional feature of the background event context that influences performance is the regularity of the interevent intervals themselves. The intervals between neutral events may be regular and predictable, occurring in what is known as a synchronous schedule, or they may be irregular and unpredictable, occurring in an asynchronous schedule. During the vigil, observers must inspect each event in order to decide whether or not it is a critical signal to which they should respond. When events occur regularly, observers are able to predict when the next event will appear. Such subjects can take short time outs from inspecting the display and do not need to monitor it continuously. Event asynchrony increases observers' uncertainty as to when the display should be monitored since potential signals can appear at any time. They must engage in continuous monitoring and cannot afford to take time outs during the vigil. Event asynchrony has been found to degrade performance efficiency (Scerbo, Warm, Doettling, Parasuraman, & Fisk, 1987; Scerbo, Warm, & Fisk, 1987). Observers of asynchronous displays typically detect fewer critical signals than monitors of synchronous displays. This phenomenon once again illustrates the considerable impact that the neutral events have on the observer's ability to detect the critical signals and also provides support for a resource theory explanation of vigilance.

2.4.1. Applications to Sentry Duty

For the sentry on watch, the background event rate is defined by the occurrence of natural stimuli around the perimeter that might mimic intruders (e.g., sounds from fish jumping in the water). While such stimuli may occur frequently or infrequently, depending on the location, they will undoubtedly occur in an asynchronous schedule. The implication here is that performance will suffer since the time period between events that must be investigated is unpredictable—observers must be on guard constantly during the entire vigil.

2.5. Stimulus Complexity

The final psychophysical factor that determines vigilance performance is stimulus complexity. Modifications of stimulus complexity may either exacerbate or eliminate the vigilance decrement, depending on the nature of the approach. For example, Jerison (1963) found that requiring observers to monitor three displays simultaneously greatly exacerbated the vigilance decrement, so much so that the decrement could be observed from the very first signal onward. On the other hand, the vigilance decrement was either eliminated or reduced in situations where observers monitored multiple sources (from 6 to 36) under conditions in which any one source could present a signal at any time (Adams & Humes, 1963; Adams, Humes, & Sieveking, 1963; Montague, Webber, & Adams, 1965). In addition, other studies (Dember, Warm, Bowers, & Lanzetta, 1984; Lysaght, Warm, Dember, & Loeb, 1984; Warm, Howe, Fishbein, Dember, & Sprague, 1984) have indicated that the decrement can be reduced by increasing the cognitive demand placed on observers, although raising the demand beyond a certain optimal level will reverse such beneficial effects and restore the decrement (Loeb, Noonan, Ash, & Holding, 1987). Thus, it is not possible to form a concise generalization as to the effects of stimulus complexity, since increasing stimulus complexity may either increase, reduce, or eliminate the decrement. It can be said that stimulus complexity does influence vigilance performance, but it cannot be predicted *a priori* exactly what its effects will be.

2.6. Summary of Psychophysical Parameters

Stimulus characteristics have been studied in depth since the inception of vigilance research in the aftermath of World War II. However, the combined impacts and interactions of all parameters concurrently have not been investigated. Thus, an exact determination of the expected overall level of performance, based on combinations of individual parameters, is not possible. Research on the psychophysical parameters of vigilance does enable identification of the stimulus features associated with improved overall vigilance performance or a reduced vigilance decrement to assist in the design phase of a task involving vigilance. Table 4 identifies these features.

Table 4. Factors That Positively Impact Vigilance Performance

Parameter	Factors That Positively Impact Performance
Sensory Modality	• Auditory signals • Combined visual and auditory signals
Signal Salience	• Highly conspicuous signals • Long duration signals
Stimulus Uncertainty	• High signal density • Regular time intervals between signals • Predictable signal locations
Background Events	• Slow rate of presentation of events • Regular time intervals between events
Stimulus Complexity	• Increased cognitive demand (to a point)

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3. TASK PARAMETERS

Some factors that impact vigilance performance stem from the manner in which the task must be performed and not from specific features inherent in the stimuli to be detected. These types of factors are discussed in this section.

3.1. Type of Discrimination

The type of discrimination required to detect critical signals or targets may be either successive or simultaneous. The primary difference between the two types of discrimination centers around whether they depend on working memory or not. Working memory is concerned with immediate conscious processing of information over a brief period of time (on the order of seconds). The concept of working memory grew from theoretical research comparing the human mind to the random access memory of a computer and may be thought of in computer terms.

Successive tasks rely on working memory for their completion, whereas simultaneous tasks do not. *Successive* tasks are absolute judgment tasks in which observers must maintain a standard in working memory and compare successively presented stimulus configurations against that remembered representation in order to make a discrimination. For example, in Mackworth's original clock task, observers had to detect when the pointer made a double jump. *Simultaneous* tasks, on the other hand, are comparative judgment tasks in which all of the information needed to make a discrimination is present in the stimuli that appear—they either do or do not contain the specified stimulus characteristic. Therefore, observers are not required to rely on working memory during the completion of simultaneous tasks. For instance, observers might be asked to detect when one spot of light appears brighter than another presented at the same time. The key feature that distinguishes the two tasks is the differential memory load imposed by them.

In general, because successive tasks impose a higher memory load, they tend to be associated with degraded performance. For example, Lanzetta, Dember, Warm, and Berch (1987) designed a vigilance task in which critical signals for detection consisted of an increase in the height of one of two bars presented simultaneously on a computer screen (simultaneous condition) or an increase in the height of both bars presented concurrently (successive condition). Stimuli were presented in the context of four different event rates (6, 12, 24, and 48 events per minute). Results indicated that the percentage of correct detections was significantly higher in the simultaneous condition (Figure 6). Furthermore, the simultaneous task appeared to be more resistant to the effects of event rate. The percentage of correct detections for the simultaneous task remained stable until the highest event rate (48 events per minute) occurred. For the successive task, on the other hand, the shift in performance occurred at a slower event rate of 24 events per minute. Such results support a resource theory of sustained attention very well.

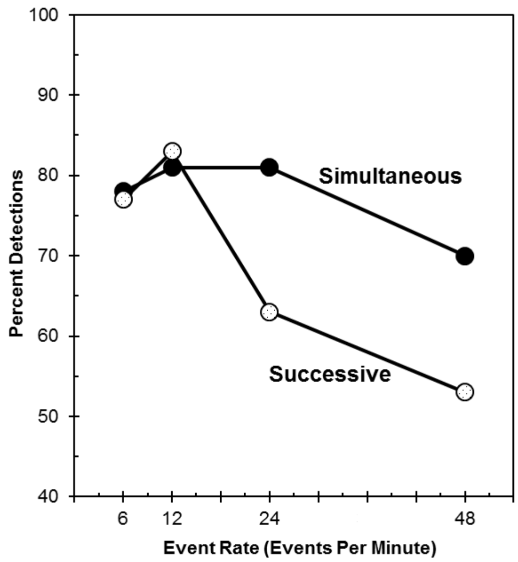

Figure adapted from Lanzetta, Dember, Warm, and Berch (1987)

Figure 6. Accuracy is Higher in Simultaneous Discrimination Tasks.

3.1.1. Applications to Sentry Duty

For the task of an observer on sentry duty, the type of discrimination primarily consists of successive discriminations. As the observer stands watch and scans the field of view, he/she must compare visual stimuli against multiple standards maintained in memory. The remembered standards consist of images of how the field of view looks when an intruder is in the water or on land, each of which can take many forms (e.g., the intruder might be crouching, standing, or crawling on land; in the sea, the intruder might be completely immersed or surfacing occasionally). The successive discrimination nature of the sentry duty task has two important implications:

- Sentry duty itself will constitute a demanding task, given the need to compare visual observations against remembered standards of the targets
- Modifying the task to make the discriminations more simultaneous in nature (e.g., by providing actual photographs of genuine and false intrusion attempts to use as standards for comparison against potential intrusion events) may help improve performance effectiveness

3.2. Knowledge of Results

Providing observers with feedback or knowledge of results typically results in an increase in the frequency and speed of signal detections and may reduce or eliminate the vigilance decrement

(Becker, Warm, Dember, & Hancock, 1995; Hitchcock, Dember, Warm, Moroney, & See, 1999). As shown in Figure 7, observers who monitored a simulated air-traffic control display to detect potential aircraft collisions during a 40-minute watch achieved higher detections overall when they received feedback. Although a decrement still occurred over time, it was not as steep for observers receiving knowledge of results.

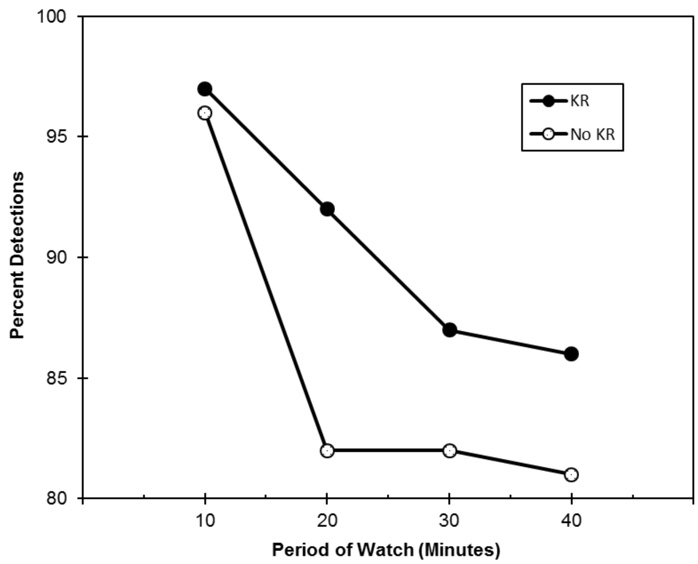

Figure adapted from Hitchcock, Dember, Warm, Moroney, and See (1999)

Figure 7. Detections are Higher with Feedback During a Vigil.

The effects of feedback may be largely motivational since the feedback does not have to be accurate in order to be effective. Providing subjects with false feedback about their performance can enhance overall performance efficiency. In addition, subjects who evaluate their own performance and provide their own feedback perform more efficiently than observers who receive no evaluative information. They also perform at the same level as subjects who receive accurate feedback from the experimenter, even though the subject-controlled feedback tends to be inaccurate. Further support for the motivational view comes from investigations of the withdrawal of knowledge of results. According to the partial reinforcement effect, partial reinforcement leads to more stable performance as compared to continuous reinforcement when the incentive is subsequently withdrawn. This phenomenon also occurs in a vigilance task when knowledge of results is withdrawn in the later phases of a vigil. Subjects who receive continuous knowledge of results in the initial portion of the session subsequently exhibit a greater decrement when the knowledge of results is withdrawn than observers on a partial feedback schedule. Thus, investigations involving false feedback, subject-controlled feedback, and the withdrawal of knowledge of results all seem to indicate that knowledge of results has a motivational rather than an instructional influence on vigilance performance.

Practically speaking, providing knowledge of results may be most useful during the training phase for a given vigilance task. In an early demonstration of the effects of knowledge of results during training, Attwood and Wiener (1969) provided an experimental group of subjects with an auto-instructional device during three 50-minute training sessions. The signal consisted of an abnormally large deflection of a voltmeter needle (30 degrees), embedded in background events of normal 20-degree deflections, presented at a rate of 50 stimuli per minute. The auto-instructional device allowed subjects to select the signal schedule; request immediate knowledge of results, signal cueing (prompting), or both; and conduct self-tests with no training aids. When tested on a standard 50-minute vigil after training, the experimental group achieved a much higher detection rate, with no increase in false alarms, as compared to the control group, which had practiced three 50-minute training sessions with no aids. Subjects in the experimental group also exhibited a preference for knowledge of results over cueing, as measured by the amount of training time spent using knowledge of results versus cueing. The authors concluded that knowledge of results during training provided both information regarding what constitutes a signal *and* motivation to perform the task.

3.2.1. Applications to Sentry Duty

The nature of the findings implies that extensive training with knowledge of results may be beneficial for personnel who perform sentry duty. Further, although it can be difficult to implement in a real-world field environment, any attempts to provide performance feedback for observers can lead to improvements in vigilance. If genuine feedback is not possible, it may be just as effective to have observers evaluate their own performance and then report their own feedback.

3.3. Multiple Observers

Research has demonstrated that team performance on a vigilance task consistently exceeds single operator performance. Wiener (1964) used a 48-minute visual monitoring task to examine performance effectiveness for four different groups. The groups consisted of one-, two-, and three-person teams and another three-person team in which the team members performed the task in isolation but had their responses combined. Participants in the isolated three-person team were seated in separate booths in the same room; they were instructed to work independently, but to consider themselves part of a monitoring team. For the isolated three-person team, a response was scored as a correct detection if at least one participant responded to a critical signal. Participants in the two- and three-person teams were seated side-by-side in front of the display, with a single response switch, and were instructed to use any system they wished to report critical signals. After experimenting with various strategies, the two- and three-person teams invariably settled on the same approach within approximately five minutes of the start of the vigil—all team members watched the display and pointed out critical signals to the individual holding the response switch. Results indicated a significant increase in the probability of signal detection as team size increased from one to two, but not from two to three. However, the performance of two- and three-person teams actually fell short of the level predicted by a probability model for independent events. In fact, the combined performance of three people performing the task in isolation was superior to the three-person team working together.

The beneficial effects of multiple observers were replicated in a more recent study of team performance (Garcia, Baldwin, Funke, Funke, Knott, Finomore, & Warm, 2011). In that study, operators performed a 40-minute visual monitoring task alone or in pairs. For the pairs, the two operators completed the task in the same room, separated by an opaque divider, but did not communicate, collaborate, or strategize with each other. The task was to monitor a simulated air traffic control display in order to identify cases in which two unmanned air systems were on a collision path (critical signal). As in Wiener's (1964) study, a response for the pair was considered a correct detection if at least one operator responded to a critical signal. Results indicated that co-operators identified an average of 25% more targets than did individuals performing the task alone (Figure 8). Results further demonstrated, however, that the superior performance came at some cost to mental workload. Electroencephalography (EEG) measures of brain activity during the vigil showed that operators in pairs used more cognitive resources to maintain performance and experienced greater mental workload as a result.

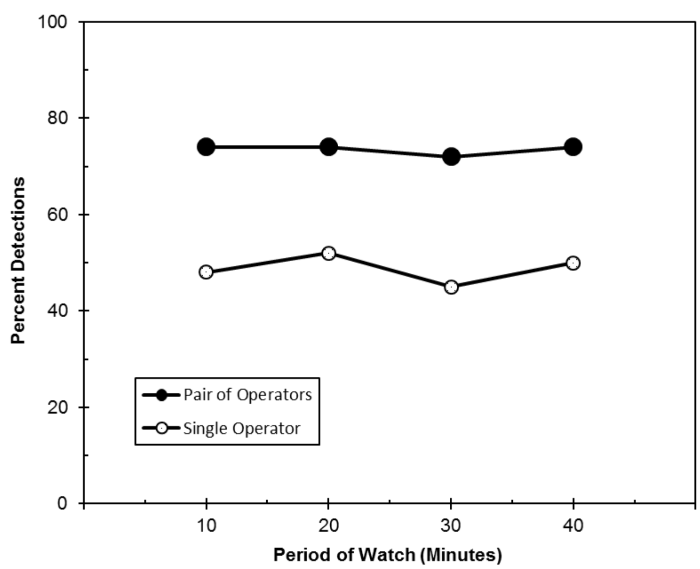

Figure adapted from Garcia, Baldwin, Funke, Funke, Knott, Finomore, and Warm (2011)

Figure 8. Pairs of Operators Detect More Targets Than Single Operators.

Research in the field of visual inspection, which frequently involves a vigilance component, has produced similar results. For example, a study conducted at the Autonetics Division of the North American Rockwell Corporation (now Rockwell International Corporation) revealed that repeated inspections significantly increased inspection accuracy for critical defects (at a slightly decreasing rate) up to a point (six independent inspections) (Harris, 1969). Little increase in inspection accuracy was noted when more than six independent inspections were used. In multiple inspector situations, the ability to distinguish defective products from non-defective products is optimized when two inspectors inspect every item, and both must reject a product for it to be classified as defective (Drury, Karwan, & Vanderwarker, 1986). In that study, the researchers examined five possible methods to incorporate re-inspection with two inspectors:

- Each inspector inspects only half the batch in parallel
- Two accepts: both inspectors inspect every item and both must accept an item for the system to accept it
- Two rejects: both inspectors inspect every item and both must reject an item for the system to reject it
- Re-inspect accepts: Inspector 2 inspects only those items accepted by Inspector 1
- Re-inspect rejects: Inspector 2 inspects only those items rejected by Inspector 1

The authors concluded that two inspectors are better than one in all cases except the parallel approach. Optimal detectability of defects occurs when the "two rejects" tactic is used.

It should be noted that performing a vigilance task in a team setting may generate distractions that interfere with the task, primarily if team member roles are unique. In Wiener's study, where team member roles were completely redundant (i.e., all observers were tasked concurrently with detecting critical signals in a single display), some groups performed the task in complete silence, while some groups conversed freely throughout the vigil. Regardless of whether observers conversed or not, it did not appear that the mere presence of others performing the task as part of a team served as a distraction during the vigil. In a somewhat different study, however, distraction caused by performing the task in collaboration with team members whose roles were nonredundant actually interfered with performance. Specifically, Hollenbeck, Ilgen, Tuttle, and Sego (1995) had 20 four-person teams work for two separate three-hour sessions on a naval command-and-control simulation. The simulation required participants to monitor the airspace surrounding an aircraft carrier and decide how to respond to incoming aircraft, based on an evaluation of various aircraft attributes. Team members had different areas of expertise and were therefore responsible for monitoring and evaluating different aircraft attributes, such that team member roles were nonredundant. While all of the evaluations and recommendations were networked across the team, team members could also send text messages to communicate information. Results indicated that, for the team that performed most poorly, all of the text messages became social as opposed to task-related about halfway through the session. The researchers concluded that the presence of others in a team setting with nonredundant roles provided a source of distraction that ultimately led to a performance breakdown.

3.3.1. Applications to Sentry Duty

The implication for sentry duty is that overall performance accuracy may be enhanced if two observers independently monitor the same area of the perimeter. However, it must be determined whether optimal performance occurs if only one observer needs to respond for an event to be considered a potential target to investigate, or if both must respond. The risk is that false alarms may be effectively doubled with two observers, and time may be wasted investigating nontarget events. Given that sentry duty roles are largely redundant, working in a team setting during the watch should not introduce distractions that would interfere with performance if the observations occur independently.

3.4. Demand Transitions

Fluctuations in demand are an important component of many real-world tasks that feature sustained attention requirements, wherein workers must perform critical tasks quickly and efficiently under high demand conditions after a sudden transition from prolonged periods of inactivity or low demand. The impacts of transitions in demand are complex, depending upon the nature of the task and the type of demand transition involved.

Krulewitz, Warm, and Wohl (1975) conducted the first experimental investigation of the effects of transitions in task demand on vigilance performance by manipulating the event rate context within a single 40-minute vigilance task. Their study indicated that a shift from a slow to fast event rate midway through the vigil reduced detection accuracy, relative to a constant fast event rate condition. Conversely, a shift from a fast to a slow event rate enhanced detection accuracy, relative to a constant slow event rate condition. The authors attributed the findings to a contrast effect, such that the fast event rate seemed comparatively more demanding to observers who initially experienced a slow event rate, and vice versa.

Gluckman, Warm, Dember, and Rosa (1993) obtained a different set of results in a study of transitions in the number of monitoring tasks to be performed during a vigil (either one task or two tasks). In contrast to the effects found with transitions in event rate, observers who initially engaged in a highly demanding dual-task monitoring condition before encountering a less demanding single-task monitoring condition performed more poorly post-shift than did the controls who engaged in continuous single-task monitoring. Such observers recovered by the end of the vigil, however, performing just as well as the single-task controls. Further, subjects who switched from a single-task to a dual-task condition did not differ from the dual-task controls post-shift.

In another examination of demand transitions, See (1992) identified yet another potential outcome. In that study, observers either experienced a constant level of signal salience throughout a 40-minute vigil, or the level of signal salience switched halfway through the vigil. The critical signal for detection consisted of a shift in the position of a pointer on a circular dial that appeared in the center of a computer screen. For low salience signals, the pointer shifted one tick mark to the right. For high salience signals, the pointer shifted two tick marks to the right. Critical signals were infrequent events that occurred with a probability of .07 throughout the vigil. Although there were clear performance differences between low and high salience signals, there were no significant effects associated with the transition in demand—the performance of switch groups simply altered to equal that of their respective control groups after the transition occurred (Figure 9). The absence of any shift in performance following the demand transition may have resulted from the more subtle nature of the transition in this study, which manifested itself only during critical signal events.

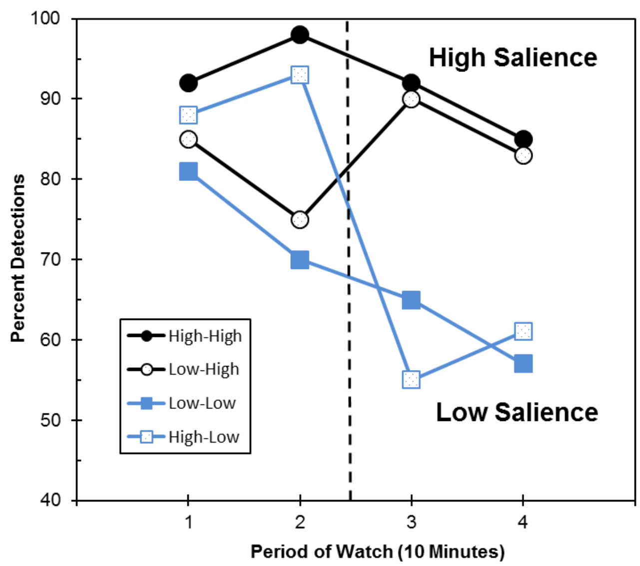

Figure adapted from See (1992)

Figure 9. Impacts of Transitions in Signal Salience on Vigilance Performance.

3.4.1. Applications to Sentry Duty

Fluctuations in demand for an observer on watch during sentry duty can have complex effects on performance effectiveness that are not readily predictable. One approach is to prepare observers for a variety of fluctuations during training so that they experience changing requirements before standing guard at a watch tower.

3.5. Payoff Matrices

One factor that influences detection performance during a vigil is the level of conservatism that observers adopt when deciding whether an event is a target or not (i.e., response bias). Observers may adopt a conservative, neutral, or lenient decision-making approach. Conservative observers decide that a given event is a target only if considerable supporting information is available. Such observers typically exhibit few correct detections and few false alarms. Neutral observers are just as likely to respond "target" as "nontarget" to a given event—they are not biased toward either response category. Lenient observers are more inclined to respond "target" to a given event. Lenient observers may exhibit many hits, but they do so at the cost of many false alarms.

One technique to influence the decision-making criterion that observers adopt is to use payoff matrices, which impose costs for false alarms and missed targets and benefits for correct detections of targets and correct rejections of nontargets. For example, observers can be encouraged to adopt a lenient criterion when the value of detections (+9) and the cost of misses (-9) are larger than the value of correct rejections (+1) and the cost of false alarms (-1). In this scenario, observers can optimize their payoff if they respond "target" when in doubt. If the payoffs are reversed, a conservative approach is encouraged. Observers can optimize their payoff if they respond "target" only when absolutely certain a target is present. With a symmetric payoff, the costs and values are neutralized, which encourages neither conservatism nor leniency.

In a study of the effects of payoffs on vigilance performance, Williges (1971) used a 60-minute vigil wherein observers had to detect brightness changes on an electroluminescent panel that occurred for 1.7 seconds (critical signal) versus 1.3 seconds (nonsignal event). Payoffs were manipulated by assigning varying numbers of points for each type of response. Points could later be redeemed for cash at the end of the experiment, though observers were not informed of the precise conversion factor or the maximum amount that could be earned. In this study, observers were also informed of the probability with which signals would occur before the session started. Results indicated that payoffs did not impact correct detections, presumably because observers knew the ratio of signals to nonsignals. However, significantly more false alarms occurred for the lenient payoff, particularly when the signal ratio was high (1:1). The pattern of results further suggested that signal probability may be a more powerful factor influencing observer criterion as compared to payoffs.

In another study; See, Warm, Dember, and Howe (1997) used a 40-minute vigil in which observers were required to detect small increments in the height of a single white line presented in the center of a gray computer screen. As in the Williges (1971) study; conservative, neutral, and lenient levels of payoff were developed via a point system in which differential values and costs were placed on correct and incorrect responses. Further, participants were offered a $25 reward for the best performance. In contrast to the Williges (1971) study, both hits and false alarms increased as the payoff shifted from conservative to lenient. Figure 10 shows correct detections for each level of payoff. Both hits and false alarms may have been affected in this study because participants did not know the signal ratios beforehand as they did in the Williges (1971) study. The difference in results may have stemmed from the fact that See *et al.* (1997) provided a very well-defined reward system that specified the point system, the implications of the point system for performance strategies, and the total amount of the payoff. These factors may be critical elements in implementing a payoff manipulation to fully impact performance.

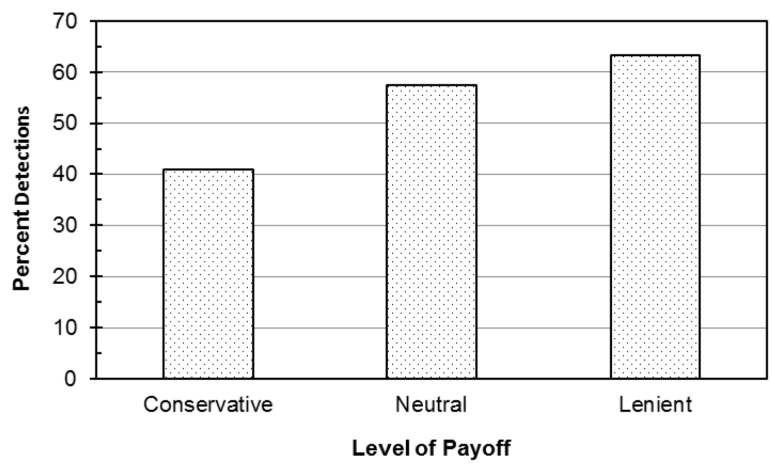

Figure adapted from See, Warm, Dember, and Howe (1994)

Figure 10. Correct Detections Increase as Payoff Shifts from Conservative to Lenient.

3.5.1. Applications to Sentry Duty

For personnel who perform sentry duty, incentives to detect targets and minimize misses may not substantially impact target detection accuracy unless properly implemented. It may be more effective to devise methods to combat the effects of low signal probabilities (e.g., by artificially injecting targets to increase the signal probability).

4. ENVIRONMENTAL IMPACTS

Environmental factors that may impact vigilance performance include temperature, ambient sounds, illumination, time of day and work/rest schedules, ambient fragrances, and body posture.

4.1. Thermal Environment

Generally speaking, ambient temperature has the greatest impact on complex tasks as opposed to tasks involving simple mental activity or reaction time. With vigilance tasks, research has shown that the impacts of the thermal environment depend upon the specific structure of the task, the severity of the thermal condition, the duration of exposure, and individual differences. Changes in ambient temperature have been associated with improved vigilance performance, decrements, and no change in performance efficiency.

The weight of empirical evidence suggests that hot environments impair vigilance performance, though facilitating effects may be seen in certain circumstances. In general, temperatures above 90°F tend to degrade vigilance performance (Hancock, 1984). Performance appears to suffer most in cases where body temperature continually increases over time, but may be facilitated if the observer experiences a high but *stable* body temperature (Bell, Provins, & Hiorns, 1964). Further, immediate entry into a hot environment may have an initial facilitating effect on performance (Poulton & Kerslake, 1965). Finally, observers with prior watchkeeping experience may be better able to resist the detrimental effects of heat (Mackworth, 1950).

Cold temperatures have not been investigated as extensively as hot temperatures. Available evidence does suggest that cold conditions can also impair vigilance performance if they are very intense or occur for very long periods of time. Hancock (1984), for example, reports a study in which observers were exposed to cold while performing lookout duties on a ship operating in Arctic conditions. As the watch period progressed, the observers exhibited longer response times. As with heat, there may be a relationship between decreasing body temperature and performance decrement. Tikuisis and Keefe (2007) found that the number of target engagements in a one-hour simulated sentry task decreased during cold conditions as compared to a thermally neutral condition. However, vigilance was unaffected by the cold, presumably because the core body temperature remained high enough. Soldiers in the study were subjected to cold strain, but this level was short of uncontrollable shivering. The room temperature during cold conditions was 32°F, and soldiers also wore a suit through which 41°F-water was circulated. These conditions brought overall core body temperatures to approximately 97.3°F.

4.1.1. Applications to Sentry Duty

For personnel who perform sentry duty, cold and hot temperature extremes may be experienced if watchkeeping occurs outdoors. Efforts to prevent body temperature from continually increasing or decreasing may help to prevent performance degradations (e.g., providing a heated/cooled shelter for periodic breaks).

4.2. Acoustic Environment

The general literature indicates that, except for short-term memory tasks, the level of noise required to impact performance consistently is very high (95 dBA or more). Simple, routine tasks may exhibit no effect or even an improvement with noise. Detrimental effects of noise are usually associated with tasks that are performed continuously without rest pauses between responses and difficult tasks such as inspection that impose high perceptual or information processing capacity demands.

Vigilance research has shown that efficiency on the task may improve, decline, or remain stable in the presence of continuous noise (Hancock, 1984). The impact is dependent on the noise quality (white or varied), noise level (above or below 90 dB sound pressure level), and degree of processing demand in the task (low or high). For example, performance of a high-demand sensory vigilance task in the context of white noise above 90 dB SPL is degraded. The degrading effects of white noise may occur at even lower intensity levels for cognitive vigilance tasks that require monitoring of symbolic or alphanumeric changes (e.g., to detect odd or even patterns in a series of numbers). On the other hand, low-intensity varied noise can actually facilitate vigilance performance for simple, low-demand monitoring tasks.

In the case of intermittent noise that occurs independent of the task being performed, performance depends primarily on noise intensity and on-off ratio. When the on-off ratio is high, low intensity noise appears to facilitate performance, while high intensity noise degrades performance. The effects of noise intensity appear to be less important at lower on-off ratios.

When intermittent noise is contingent upon observer responses, performance effectiveness improves. In one study, observers in a three-hour vigilance task received a broadcast from a local radio station based on their detection performance or heard the radio continuously, regardless of their performance. In the radio contingent condition, the radio was turned off after a missed signal and turned on when a signal was detected. Performance was significantly better in both radio conditions as compared to a control condition with no radio. However, observers in the radio contingent condition did not exhibit a performance decrement over time. This finding may have more to do with the knowledge of results provided in the radio contingent condition than with the presence of the background noise *per se*. Interestingly, Fox (1973) reports studies in which the presence of background music alone improved defect detection during a visual inspection task by about 10% if used sparingly for short periods at prescribed intervals—in this case, the background music did not provide any feedback regarding response accuracy for observers.

4.2.1. Applications to Sentry Duty

The nature of the findings reported here suggests that performance during sentry duty might be enhanced in the presence of intermittent low intensity noise with a high on-off ratio.

4.3. Illumination

Illumination levels would appear to be a logical environmental variable to include in vigilance research, given the associations between light, alertness, and wakefulness. However, comparatively little research has been devoted to the effects of illumination on vigilance performance. In a review of the general alerting effects of light, Cajochen (2007) noted that most studies of the alerting properties of light have been conducted during the nighttime hours, simulating night shift work, and unequivocally demonstrate that light has alerting properties when compared with a dim light condition at night. However, recent work extending the research to daytime studies shows that light exposure can enhance alertness even during daytime hours. Further, multiple studies have demonstrated the superiority of short wavelength light of around 470 nanometers or lower (in the indigo to blue range). Namely, shorter wavelength light is associated with lower sleepiness ratings, decreased auditory reaction times, and fewer attentional failures such as lapses in attention.

When examining the effects of illumination level specifically on vigilance performance, Boyce (1970) found that illumination level had very little effect on accuracy during a continuous two-hour task that required target scanning, pattern recognition, and visual acuity. The primary effect of illumination was on speed—at low illumination levels, operator speed was degraded and the variability of speed increased. Results indicated that the optimum level of illumination for superior prolonged performance, as measured by speed, was in the range of 2000 to 4000 lux (by comparison, the illumination in a typical office conference room is 200 to 500 lux). Subjective impressions of the illumination were also optimal at the 2000 to 4000 lux range. Reports of mental fatigue were lower and physical complaints of eye strain and blurred vision were minimized. In addition, operators rated this level of illumination as the most satisfactory.

4.3.1. Applications to Sentry Duty

Equipping watch towers with shorter wavelength light at levels of illumination in the range of 2000 to 4000 lux may help sentry duty guards maintain alertness.

4.4. Time of Day and Work/Rest Schedules

Both the time of day during which a vigil is performed and the timing of work/rest periods impact performance effectiveness.

4.4.1. Time of Day Effects

The overall level of vigilance performance generally improves from morning to afternoon or evening testing (Davies & Parasuraman, 1982). The improvement in detection accuracy is frequently accompanied by an increase in false alarms, indicating that observers achieve a higher level of correct detections simply by designating more events as critical signals. This effect suggests that time of day may primarily impact the observer's decision-making criterion rather than the basic ability to distinguish critical signals from nontargets. Further, the results of several studies suggest the night shift is the worst time of day for tasks requiring vigilance and inspection:

- Drury (1974) reported that inspectors working night shifts are more likely to miss defects
- Pigeau, Angus, O'Neill, and Mack (1995) found that a vigilance decrement occurred in a real-world NORAD task during the night shift
- Wilhelmsen, Ostrom, and Kanki (2002) indicated that the swing shift appeared to be least accurate in estimating the length of cracks during aircraft inspections
- McCallum *et al.* (2005) demonstrated late night and early morning shifts for airport baggage screeners were associated with degraded attentional switching and poorer performance
- Horne, Anderson, and Wilkinson (1983) found the ability to distinguish auditory signals from nonsignals declined during 60 hours of continuous wakefulness (as measured in a 30-minute vigilance task at five different times throughout the 60-hour period)—performance declined most sharply during the usual sleep period and leveled out during the daytime; a similar study (Horne & Pettitt, 1985) revealed that performance could be maintained at baseline levels for up to 36 hours of deprivation if monetary rewards were provided for correct responses

4.4.2. Work/Rest Schedules

In his initial laboratory studies of the vigilance phenomenon, Mackworth (1950) discovered the benefits of providing frequent rest periods. Specifically, alternating 30-minute periods of watch with 30 minutes of other work prevented the typical vigilance decrement. Similarly, in a study of the effects of signal salience and duration, Adams (1956) demonstrated that the decline in efficiency over time could be reversed following a rest period. Observers in that study monitored a circular white display for 110 minutes in order to detect a blip of light in the center of the screen. A final 10-minute trial occurred after a 10-minute rest period. Two levels of brightness and two levels of stimulus duration were used. All groups exhibited a steady decline in detection efficiency during the vigil, and all groups exhibited a gain after the 10-minute rest period.

In a comprehensive investigation of 15 different task and environmental factors, Bergum and Lehr (1963) found that the use of spaced rest periods was one of the most effective variables to combat the vigilance decrement, consistently yielding high levels of individual performance. In their study, inexperienced National Guard trainees from the Army Training Center at Fort Bliss, Texas, monitored a circular display of 20 lights that were illuminated in sequence. The target for detection consisted of failure of a lamp to light in its normal sequence. One group of participants worked continuously for the entire 90-minute vigil. The second group was permitted a 10-minute rest period after every 30 minutes of watch. Observers in the rest group exhibited an almost constant high level of performance over the entire testing session, whereas the no-rest group showed a typical vigilance decrement (Figure 11). These effects occurred at both high and low signal rates.

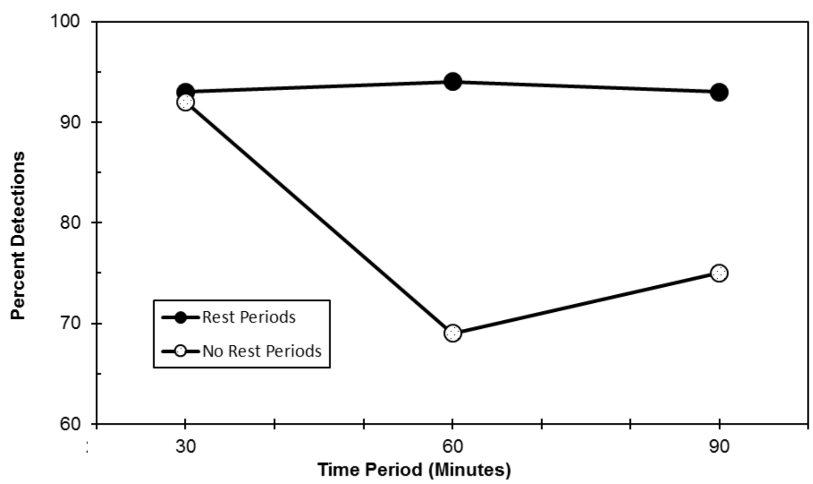

Figure adapted from Bergum and Lehr (1963)

Figure 11. Rest Periods Can Help Maintain a High Level of Performance Accuracy.

These results are partially confirmed in the most recent investigation of the impact of rest breaks on vigilance performance (Ross, Russell, & Helton, 2014). Subjects received a one-minute rest break at 20 minutes and another one-minute rest break at 30 minutes into a 40-minute vigil that required discrimination of line lengths. The first break disrupted the typical vigilance decrement and enabled some recovery in subjects' ability to discriminate signals from nonsignals. This effect was not replicated during the second break, possibly because one minute was not long enough for recovery by the end of the vigil.

Further evidence for the beneficial effects of rest breaks can be seen in the visual inspection literature. Inspectors frequently perform their tasks for prolonged periods of time that can induce vigilance effects. One of the principal recommendations to help prevent the occurrence of a vigilance decrement or reduce its magnitude during visual inspection is to alter the schedule so that inspectors spend no more than 30 minutes at a time inspecting parts (Purswell & Hoag, 1974; Swain, 1967). Colquhoun (1959) and Purswell and Hoag (1974) advocated a five-minute rest break after 30 minutes of inspection work, as opposed to the traditional work/rest schedule of a 15-minute break every four hours, to relieve the perceptual and cognitive demands of inspection. In Colquhoun's (1959) study of machine-paced visual inspection, for example, inspectors who received a five-minute break after 30 minutes missed an average of 9.9 defects in the second half hour, as compared to an average of 44.1 missed defects in the group that performed continuously for 60 minutes. In a similar investigation, Swain (1967) demonstrated that limiting the inspection period to 30 minutes reduced the number of missed defects during inspection of critical parts for military weapons, as compared to the commonly used full-day schedule of inspection. The "rest" break does not have to be a non-working break, either. Simply alternating inspection or vigilance with some other task approximately every 30 minutes is sufficient.

4.4.3. Applications to Sentry Duty

Observers on sentry duty will be able to perform more effectively if 30-minute periods of watch are interspersed with five-minute "rest" breaks or 30 minutes of a different type of work. For example, the utility of cross training personnel to permit alternating periods of sentry duty with periods of alarm display monitoring should be explored. Poor performance associated with the night shift must be recognized and managed appropriately by implementing countermeasures reported elsewhere in this review.

4.5. Fragrance Administration

Various studies have demonstrated that introducing certain fragrances into the environment during a vigil may enhance signal detections. Some aromas can be quite salient and can play important roles in emotion, recall, and recognition (Richardson & Zucco, 1989). There is also evidence that some fragrances can enhance alertness and that some can reduce stress, at least on a short-term basis. While this evidence is partially anecdotal (King, 1988), much of it comes from empirical research using both psychophysiological and self-report techniques (Lorig & Schwartz, 1988; Schwartz, Whitehorn, Hernon, & Jones, 1986).

In the first empirical demonstration of the effects of fragrances on sustained attention, Warm, Dember, and Parasuraman (1991) found that performance accuracy was higher when subjects received short whiffs of either muguet (lily of the valley) or peppermint fragrances throughout the vigil, as compared to control group subjects who received only whiffs of pure air. The vigilance task involved detecting when two lines that were repeatedly presented with a separation of 10 mm were instead presented with a separation of 12 mm. Although detection accuracy was higher overall, fragrance administration did not prevent the occurrence of the vigilance decrement itself (Figure 12). Further, fragrance administration did not change subjective reports of mood and workload, indicating the task was stressful and demanding, even though both fragrances had been rated as pleasant.

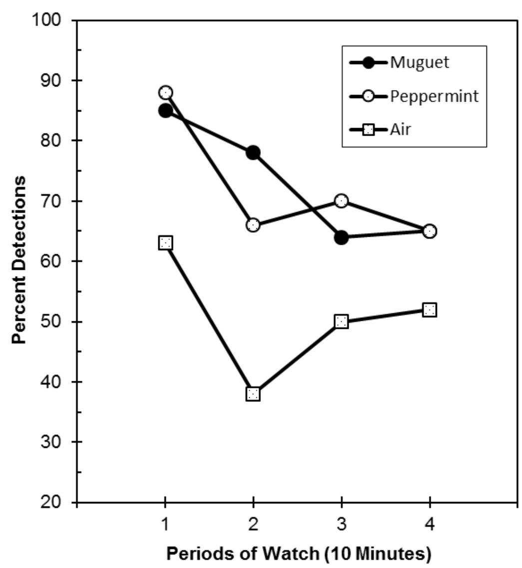

Figure adapted from Warm, Dember, and Parasuraman (1991)

Figure 12. Overall Vigilance Performance is Superior with Pleasant Fragrances.

In a similar study, Jones, Ruhl, Warm, and Dember (1999) examined the effects of both pleasant (vanilla bean and clementine) and unpleasant (butyric acid) fragrances during the same vigilance task used in the 1991 study. Of these fragrances, butyric acid was rated as alerting, whereas clementine and vanilla bean were rated as relaxing. Results confirmed and extended previous findings demonstrating that exposure to pleasant odors can enhance vigilance performance. Namely, the clementine and vanilla bean scents were associated with elevations in the overall level of signal detection in comparison to an unscented air control group. The enhancement in signal detections was not accompanied by an increase in false alarms. Given that butyric acid (a stimulating but unpleasant odor) did not improve performance, the authors concluded that the use of fragrances to boost vigilance performance seems to be limited to pleasant scents.

Although the research did not involve vigilance *per se*, a study by Baron and Bronfen (1994) demonstrated that performance on a word construction task was significantly enhanced by the presence of fragrance (either Glade *Powder Fresh* or Glade *Spiced Apple* sprayed in the room where the subject worked) in both low and high stress conditions. Specifically, subjects exposed to fragrances completed more items in the word construction task than did subjects in the no-fragrance control group. Further, pleasant fragrances mitigated the negative aftereffects of stress, as demonstrated by superior performance on an additional message decoding task after the stressful conditions of the main task had concluded. Again, subjects in the two fragrance conditions decoded significantly more letters than those in the control group. In a second study, the authors demonstrated similar performance effects on the word construction task for a lemon scent. In addition, Study 2 indicated that the effects on work-related behavior appeared to be mediated in part by increments in positive affect. Namely, participants exposed to pleasant fragrances engaged in significantly more immediate and delayed helping behavior than those not exposed to such fragrances—many previous studies have indicated that helping behavior tends to be enhanced by positive affect.

In a study of the effects of exposure to pleasant, ambient fragrance on alertness during a simulated driving task, Baron and Kalsher (1998) demonstrated that the presence of a lemon aroma significantly enhanced performance (the average amount of time participants maintained the simulated vehicle within the lane markers). A follow-up study suggested these effects stemmed, at least in part, from the fact that pleasant fragrances enhance *both* alertness and positive affect. Participants rated their own moods as more positive and reported finding it easier to remain alert while performing the simulated driving task in the presence of the lemon aroma than in the absence of fragrance. Because exposure to a pleasant fragrance also resulted in enhanced performance, however, it appeared that the alerting or activating effect predominated for the simulated driving task used in the study.

Finally, in a direct application to sentry duty tasks, 11 soldiers completed three-hour marksmanship sessions in a rifle simulator (McBride, Johnson, Merullo, & Bartow, 2001). A peppermint fragrance was administered intermittently according to one of three schedules:

- Experimenter administered (six times every 30 minutes)
- Self-administered at will
- No fragrance

The fragrance was delivered at an intensity that was determined to be at, or just above, detection threshold. Results indicated that the administration of the peppermint fragrance did not improve target detection, target latency, or friend-foe discrimination. The authors postulated that the absence of an effect for fragrance may have been due to the very low concentration used in their study as compared to other studies reported in the literature, which typically use levels that are much more salient. This supposition has not been confirmed experimentally.

4.5.1. Applications to Sentry Duty

For observers on sentry duty, the results of studies of fragrance administration suggest the possibility of using salient pleasant fragrances as one technique to maintain or restore alertness during the vigil. For instance, devices that release pleasant, alerting fragrances at times when observers show overt signs of fatigue or waning attention (e.g., head nodding and eyelid closure) might restore alertness and prevent adverse outcomes such as security breaches. Alternatively, fragrance-releasing devices that observers can activate themselves when they feel they are growing fatigued or sleepy might also prove effective.

4.6. Body Posture

The impact of body posture on vigilance performance has not been as thoroughly investigated as other environmental factors. Two relevant studies provide somewhat conflicting results regarding the benefits of an upright versus a seated posture. One study found positive effects for a standing versus sitting posture on vigilance performance in 16 sleep-deprived subjects during 28 hours of continuous wakefulness (Caldwell, Prazinko, & Caldwell, 2002). Subjects completed a vigilance task a total of 12 times throughout the 28-hour period, half while standing and half while sitting. The Psychomotor Vigilance Task (PVT) used in the study is a simple reaction time test that is known to be sensitive to sleep loss and degradations in attention. The device visually displays numbers in milliseconds that increase rapidly in sequence for up to 1500 milliseconds until the observer responds by pressing a button on the device (Figure 13). Results indicated that PVT reaction times and lapses (failures to respond to the display before 1500 milliseconds) were maintained at nearly well-rested levels when participants stood upright. By contrast, reaction time and attention deteriorated when participants were seated during the testing. EEG data further indicated that theta activity—brain waves associated with fatigue, impaired alertness, and vigilance decrements—progressively increased as a function of sleep loss, but standing upright significantly reduced this effect.

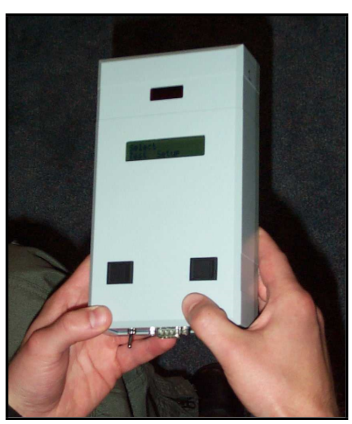

Figure 13. PVT Device.

In a study that used tasks more representative of sentry duty, 12 experienced security operators performed a 20-minute task simulating an intrusion detection task that prevents passengers from entering a secure area followed by a 20-minute simulated X-ray baggage screening session (Drury, Hsiao, Joseph, Joshi, Lapp, & Pennathur, 2008). Three different workplace arrangements were examined:

- Sitting on a high chair viewing a screen placed on top of the X-ray machine (current workplace)
- Standing
- Conventional desk-sitting

Results revealed no performance effects associated with posture. The only significant effects of posture were on non-work related movements for the intrusion detection task and on participant comfort. Most non-work related movements occurred when sitting at a desk and the fewest occurred when sitting on a high chair. Discomfort increased from the seated postures to the standing posture.

4.6.1. Applications to Sentry Duty

The nature of the results here suggests that sentries should remain standing during the watch. While the X-ray screening task did not show any benefits for standing versus sitting, there is evidence that the brain waves associated with fatigue, impaired alertness, and vigilance decrements can be reduced if sleep-deprived individuals stand upright. Standing upright may also provide a countermeasure to help combat the poor performance associated with night shift work.

5. PHARMACOLIGICAL EFFECTS

The impacts of stimulants, depressants, and other products on vigilance performance have been extensively researched. Such products include caffeine, alcohol, and nicotine. The use of caffeine, a socially acceptable stimulant, has been studied to determine whether coffee drinking may improve vigilance performance. Gum chewing has recently been investigated as a possible easy means to boost performance. While gum itself is not a stimulant, it is an external product that observers might legitimately use during task performance. Unlike some stimulants, chewing gum is a legal substance, and it does not carry any of the negative connotations associated with some drugs (e.g., tobacco use). For these reasons, studies of the impacts of gum chewing are included in this section of the paper.

5.1. Caffeine

Multiple laboratory studies have shown that caffeine has a beneficial effect on vigilance performance. During a one-hour auditory vigilance task, participants performed significantly better when they took 200 mg of caffeine than when they received a placebo (Fagan, Swift, & Tiplady, 1988). Similarly, subjects given 3 mg of caffeine per kilogram of body weight were more accurate and responded more quickly in a visual task that involved detecting sequences of three consecutive odd or even digits presented at a rapid pace of 100 digits per minute (Smith, Rusted, Savory, Eaton-Williams, & Hall, 1991). While caffeine did not modify the vigilance decrement, it did eliminate the typical post-lunch dip in performance. No effects were observed when a smaller dose of 60 mg of total caffeine was used. The beneficial effects of caffeine were also found to apply to a demanding 12-minute vigilance task that presented stimuli at a rate of 57.5 events per minute (Temple, Warm, Dember, Jones, LaGrange, & Matthews, 2000). Stimuli consisted of light gray capital letters (*O*, *D*, and a backwards *D*) against a visual noise mask consisting of unfilled circles on a white background—the letter *O* represented the critical signal for detection. A caffeine dose of 1.1 mg per kilogram of body weight improved overall performance and moderated the vigilance decrement (Figure 14).

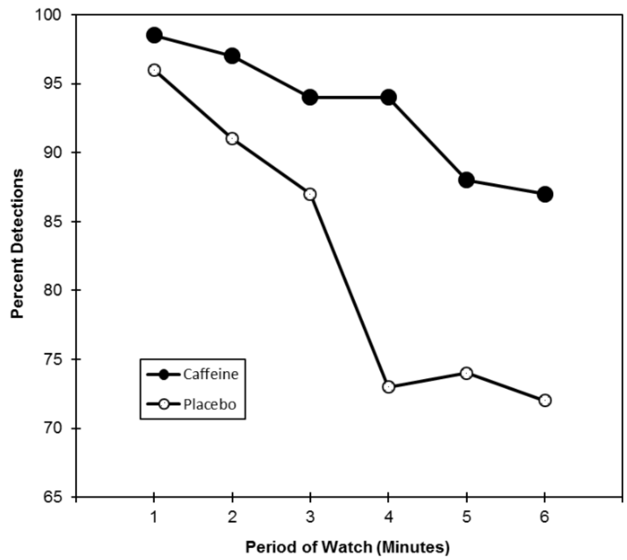

Figure adapted from Temple, Warm, Dember, Jones, LaGrange, and Matthews (2000)

Figure 14. Caffeine Boosts Overall Performance and Reduces the Decrement.

The benefits of caffeine have also been demonstrated specifically for sentry duty tasks (Johnson & Merullo, 1996; Johnson & Merullo, 1999; Kamimori, Johnson, Belenky, McLellan, & Bell, 2004; Tikuisis, Keefe, McLellan, & Kamimori, 2004). Two studies by Johnson and Merullo (1996, 1999) confirmed the results of traditional vigilance research for simulated sentry duty. In their first study, target detection time for 12 males and 12 females was significantly improved during a three-hour simulated sentry task when a 200 mg caffeine tablet was ingested. Further, there was no vigilance decrement in the caffeine condition. In their second study, they further demonstrated that 200 mg of caffeine not only eliminated the decrement in target detection speed with time on task but also reduced errors in friend-foe discriminations. Similarly, Tikuisis *et al.* (2004) found that caffeinated chewing gum restored target engagement speed (target detection) during a one-hour marksmanship task on a combat rifle simulator, following 22 hours of active wakefulness. Finally, Kamimori *et al.* (2004) obtained similar results with caffeinated gum during a 55-hour Army training exercise that involved two realistic vigilance tasks. During the first task, 30 male soldiers were instructed to fire a single shot at targets, which appeared randomly four times during a 40-minute period. In the second task, soldiers observed and recorded actions occurring in and around an assigned observation point for 90 minutes. One relevant activity occurred randomly every 10 minutes (e.g., a pen light being turned on to simulate the enemy reading a map). With the caffeinated chewing gum (100 mg per stick), soldiers were able to maintain performance on both vigilance tasks as compared to the placebo condition.

5.1.1. Applications to Sentry Duty

Caffeine may help observers on sentry duty maintain alertness and performance effectiveness during the watch. Both caffeinated beverages and caffeinated chewing gum may be beneficial.

5.2. Alcohol and Nicotine

There is evidence that alcohol impairs vigilance performance, whereas tobacco smoking can prevent the vigilance decrement from occurring. In a study of the combined effects of alcohol and nicotine, Tong, Henderson, and Chipperfield (1980) analyzed performance in the context of a 72-minute auditory vigilance task. Participants listened to a continuous sequence of digits in order to detect the occurrence of three consecutive odd but unequal digits. Four groups of individuals participated—no alcohol and no nicotine, both alcohol and nicotine, alcohol only, and nicotine only. For participants in an alcohol group, alcohol was administered in the form of 35% ethyl alcohol to produce a blood alcohol content of .06%. For participants in a nicotine group, standard cigarettes with nicotine and tar contents of 1.3 mg and 18 mg, respectively, were used before and during the vigil. Results indicated that correct detections were significantly lower and a vigilance decrement occurred when alcohol was consumed. The use of nicotine prevented the typical decline in vigilance over time. The authors suggested that nicotine may mitigate the detrimental effects of alcohol on performance.

5.3. Gum Chewing

Interestingly, several recent studies have reported the beneficial effects of gum chewing on vigilance performance, alertness, and stress. Initial forays into this line of research established that gum chewing can both maintain and increase self-rated levels of alertness (Johnson, Jenks, Miles, Albert, & Cox, 2011; Johnson, Muneem, & Miles, 2013).

Subsequent studies then extended the findings specifically to vigilance research, inferring that observed impacts are mediated by the demonstrated effect of gum chewing on alertness. Tucha and Simpson (2011) found that gum chewing had beneficial effects on sustained attention, as measured by smaller increases in reaction times to target stimuli during the last 10 minutes of a 30-minute vigil (compared to a no-gum condition). Morgan, Johnson, and Miles (2013) demonstrated that degradations in accuracy, increases in reaction time, and declines in subjective ratings of alertness were all attenuated for the group that chewed gum during a 30-minute auditory vigilance task that imposed considerable working memory demands—while listening to a random presentation of the digits 1-9 at a rate of one per second, participants were required to detect target sequences consisting of odd-even-odd digits (Figure 15). Allen (2013) used a variety of techniques to study possible links between gum chewing and performance, alertness, and stress. Of note here, results suggested that gum chewing could reliably maintain alertness, enhance reported performance at work, and attenuate decrements in vigilance.

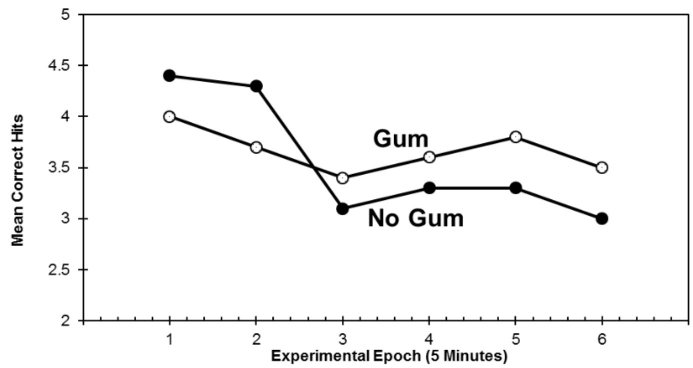

Figure adapted from Morgan, Johnson, and Miles (2013)

Figure 15. Gum Chewing Reduces the Vigilance Decrement.

5.3.1. Applications to Sentry Duty

Gum chewing, an extremely simple countermeasure to implement, may help observers on sentry duty maintain alertness and performance effectiveness throughout the vigil.

6. INDIVIDUAL DIFFERENCES

Individual differences in the ability to sustain attention have been researched since vigilance issues were first identified in World War II. Although dramatic differences in vigilance performance exist between individuals, evidence indicates that within-subject performance is consistent over time. This trend suggests that studying differences between individuals might reveal the parameters important for maintaining vigilance. The primary factors that have been investigated include gender, age, intelligence, and personality factors such as introversion/extraversion, cognitive style (field dependence/independence), optimism/pessimism, and locus of control (internal or external).

6.1. Gender

Multiple studies have investigated the role of gender in the fields of vigilance and visual inspection. Results have been conflicting. Studies have found females to be superior to males, males to be superior to females, or no differences between males and females (Reinerman-Jones, Matthews, Langheim, & Warm, 2011; See, 2012). Wiener (1975), for example, reports 11 vigilance studies that examined gender. Six studies found no significant differences between the genders at all, two found that males were superior, and three reported non-significant main effects of gender but significant interactions with other variables. Overall, Berch and Kanter (1984) concluded that any differences between males and females are usually quite small and serve little or no practical or theoretical purposes.

6.2. Age

As with gender, age is an unreliable predictor of vigilance performance (Reinerman-Jones, Matthews, Langheim, & Warm, 2011). There is some suggestion that younger observers perform better than older individuals, particularly when signal/noise discriminations are difficult and the background event rate is rapid. Further, an extensive longitudinal study suggested that detection efficiency deteriorated markedly around the age of 70 years (Quilter, Giambra, & Benson, 1983). However, this finding has not been confirmed, and a number of cross-sectional studies have not revealed any age-related differences in vigilance performance. In sum, age does not appear to be a strong contributor to individual differences in vigilance performance.

6.3. Intelligence

While there is some evidence of positive correlations between levels of normal adult intelligence and vigilance, comprehensive reviews have reported essentially no significant relation between measures of general intelligence and vigilance (Reinerman-Jones, Matthews, Langheim, &

Warm, 2011). In fact, McGrath (1963) concluded that efforts to select personnel for vigilance tasks based on general intelligence are a dead end. He also was unable to find any reliable predictors of vigilance when investigating related measures of intelligence and aptitude; including mathematical reasoning, visual speed and accuracy, memory span, mechanical and clerical aptitude, visual pursuit, proofreading, and audio-visual checking. However, more recent research suggests the case may not be entirely closed, given current evidence for correlations between working memory and intelligence. Along these lines, impaired working memory has been shown to degrade performance in successive discrimination vigilance tasks that require comparing stimuli against a remembered standard in working memory.

6.4. Introversion/Extraversion

Introverts typically exhibit a superior overall level of monitoring performance as compared to extraverts, primarily due to an inherently higher level of sensitivity to stimulation (Berch & Kanter, 1984; Koelega, 1992). For example, introverts consistently detect auditory signals at lower thresholds than extraverts, and they are unable to tolerate the higher intensities of noise that extraverts can endure. When completing vigilance tasks, introverts tend to be more cautious in responding, and they are better able than extraverts to actually distinguish targets from nontargets. While introverts perform more accurately overall in sustained attention tasks, research has shown they are no better than extraverts at maintaining this level of efficiency over time (Koelega, 1992).

6.5. Cognitive Style

Cognitive style (field dependence/field independence) characterizes people by the degree to which they are influenced by cues in the perceptual field. Some people have a tendency to perceive complete patterns rather than their separate components and therefore have greater difficulty analyzing a part separately from an overall pattern. Such individuals are classified as *field dependent*. Field dependent individuals have a more "gestalt" or holistic perceptual style and are more likely to attend to an item in its entirety rather than to its details. Other people are better able to separate components from the wider pattern and focus only on the relevant aspects—they are classified as *field independent*. Field independent people tend to focus on details and ignore irrelevant cues. Available evidence indicates that field independent individuals perform better on vigilance tasks (Berch & Kanter, 1984).

6.6. Optimism/Pessimism

Optimism and pessimism are personality constructs that represent inclinations for either positive or negative expectations. While they appear to lie at opposite ends of a single dimension, optimism and pessimism are only moderately negatively correlated when assessed separately.

Investigations of optimism/pessimism suggest that effects on vigilance performance may be dependent on task characteristics. For example; when completing a brief, but highly demanding and stressful visual vigilance task that presented stimuli at a rate of 57.5 events per minute; pessimists exhibited poorer overall performance and a steeper vigilance decrement than optimists (Helton, Dember, Warm, & Matthews, 1999) (Figure 16). Pessimists also committed more false alarms throughout the vigil. In contrast, during a lower event rate task (30 events per minute) involving easier discriminations, optimism/pessimism did not significantly affect performance (Szalma, Hancock, Dember, & Warm, 2006).

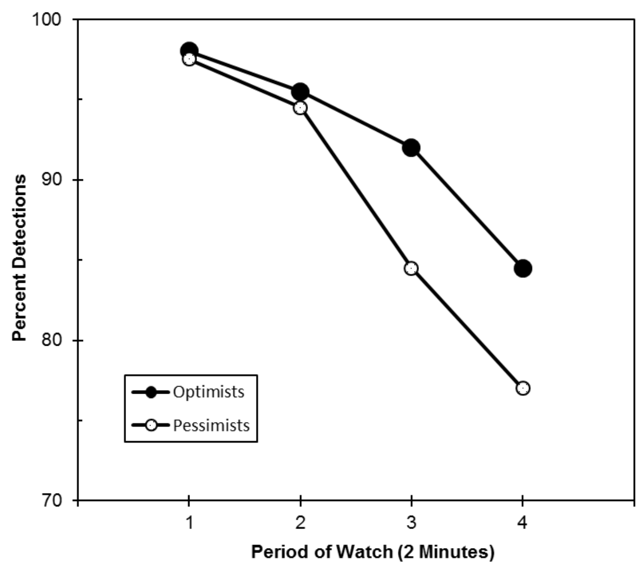

Figure adapted from Helton, Dember, Warm, and Matthews (1999)

Figure 16. Pessimists Perform More Poorly in Highly Demanding Vigilance Tasks.

6.7. Locus of Control

The locus of control dichotomy categorizes individuals according to whether they believe they control their own destiny (*internal locus of control*) or whether they believe their fate is contingent on external factors beyond their control (*external locus of control*) (Rotter, 1966). During vigilance task performance, observers have no control over where and when targets will occur, and their responses have little impact on the time course of signal appearances. With that in mind, it is not surprising that research has demonstrated superior vigilance performance for individuals with internal locus of control.

6.8. Other Personality Variables

Other personality factors have received attention recently and are being considered as candidates for a multivariate test battery to assist in personnel selection for vigilance tasks and predictions of performance effectiveness (Finomore, Matthews, Shaw, and Warm, 2009; Reinerman-Jones, Matthews, Langheim, & Warm, 2011). These factors include boredom proneness, a proclivity for cognitive failures, and conscientiousness. Signal detection varies inversely with the degree of *boredom* experience during a vigil; hence, individuals who are more vulnerable to boredom exhibit degraded performance. Individuals high in *cognitive failures* (lapses of attention and absent-mindedness) perform more poorly on vigilance tasks and generally perceive such tasks as more mentally demanding than their low cognitive failure counterparts. Recent research has also demonstrated a positive relation between vigilance performance and *conscientiousness* (which encompasses characteristics such as competence, dutifulness, order, achievement striving, self-discipline, and deliberation), though additional research is needed.

Finally, given the vast number of personality variables that may potentially relate to vigilance performance, there have been efforts in recent years to develop a taxonomy that blends multiple traits into a smaller number of higher-order terms. One such taxonomy is the *Five Factor Model* that includes the traits of extraversion, neuroticism, conscientiousness, agreeableness, and openness. Such traits are invariant across age, gender, and culture and have demonstrated success in predicting a variety of abilities and behaviors. While vigilance research to date has shown relationships between two of the *Five Factor Model* traits (extraversion and conscientiousness), additional work is needed to reach any conclusive determinations about its utility as a whole for predicting vigilance performance.

6.9. Applications to Sentry Duty

Introverted individuals who are field independent and have an internal locus of control may represent the best personnel to perform sentry duty effectively. However, many additional factors are currently being explored, and optimal screening techniques are still in their infancy.

7. HUMAN-SYSTEM INTEGRATION FOR VIGILANCE TASKS

Given the pervasiveness of the vigilance decrement, tasks that require personnel to sustain attention for prolonged periods of time must be carefully designed to optimize the strengths of the human detector and minimize the weaknesses. The advantages and disadvantages of incorporating automated functions into the system to help overcome human operator weaknesses must also be evaluated. Introducing additional technology does not always solve problems associated with vigilance and may serve only to degrade performance further.

7.1. Fitts List for Human-Machine Allocation

In order to understand how to optimize human-system integration for vigilance tasks, it is beneficial to examine the human-machine function allocation first proposed by Fitts (1951). The human-machine function allocation is used to determine if a person or a machine could better perform the function required by the system in order to optimize performance, efficiency, safety, and quality. The *Fitts List* that was developed provides a series of statements regarding the abilities of humans and machines that can be used to derive the allocation of function/task assignments (Table 5).

Table 5. Fitts List for Human-Machine Allocation

Humans Are Better At:	Machines Are Better At:
• Detection of nuances	• Operating in hostile environments
• Perceiving a wide variety of stimuli with the five senses	• Repetitive, precise operations
• Pattern perception	• Fast response to signals
• Relevant recall of information	• Processing information in short time periods
• Creativity	• Performing with high accuracy
• Reaction to low-probability events; i.e., accidents and faults	• Sensitivity to stimuli beyond human sensitivity (e.g., infrared)
• Flexible problem solving	• Multi-tasking
• Using experience in the present	• Exerting large amounts of force smoothly
• Performing when overloaded	• Insensitivity to extraneous factors such as mood
• Inductive reasoning and hypothesizing	• Deductive reasoning and logic

Although the *Fitts List* is an oversimplification of function allocation, it provides an adequate approximation that captures the most important concerns related to automation. The list is still used today; however, the focus is generally on solving issues of collaborative, dynamic allocation rather than sole allocation of a function to either a human or machine.

7.2. Strengths and Weaknesses of Human Detectors

In terms of vigilance tasks, the *Fitts List* helps provide an understanding of the strengths and weaknesses of the human detector. First, humans are able to simultaneously detect a wide variety of stimuli with all five senses and integrate such sensations into meaningful patterns to arrive at a consistent, coherent understanding of the environment around them. In so doing, humans are capable of detecting subtleties that may signify important differences. Second, humans have the ability to quickly recall relevant information that may be brought to bear on the current situation. Taken together, these two abilities represent what are called bottom-up processing and top-down processing. Bottom-up processing occurs based on incoming sensations, whereas top-down processing occurs based on information retrieved from memory. Thus, when perceiving environmental stimuli, humans rely not only on basic sensations but also relevant information from past experiences and knowledge.

Another strength of the human detector is the ability to reason inductively. Namely, humans are able to form generalizations based on individual instances. For example, when detecting three intrusion attempts that occur after hearing a branch snapping, the human detector is able to generalize from those events to form a basic conclusion—the sound of a branch breaking may signal an attempted perimeter intrusion. When that occurs, the human detector may draw upon previous experience to heighten alertness and bring other senses to bear.

Finally, while humans may have difficulties sustaining attention and detecting low-probability events, they are generally superior in their ability to respond when such low-probability events occur. This superior ability to respond stems in part from human abilities for pattern perception and information recall and in part from the capacity for creativity and flexible problem solving. Humans are good at piecing together disparate sources of information to understand the underlying pattern, and they are able to think outside the box to derive a creative solution if needed. That is, humans are not restricted to only those solutions that have worked in the past. They can develop a completely unique solution that fits the specific features of the current situation if needed.

By the same token, it is important to realize that these very strengths can also become weaknesses. For example, human detectors are able to use both bottom-up and top-down processing to analyze a situation. This ability is a strength because people can capitalize on past experience to help understand incoming sensations. This ability can also be a weakness, as when human detectors become biased toward those areas of the field of view that tend to be associated with attempted intrusions, potentially leading to neglect of other areas.

While *Fitts List* provides an understanding of the capabilities and limitations humans bring to a vigilance task, it does not identify the precise strengths and weaknesses of the human detector performing a vigil. At present, no such list comparable to *Fitts List* exists specifically for vigilance. In general, the strengths of a human detector in a vigil include the ability to combine multiple basic sensations to detect complex patterns and the ability to use information stored in long-term memory to understand and make sense of those patterns. The predominant weaknesses of a human detector in a vigil include the following:

- Inability to detect inconspicuous or brief targets reliably
- Susceptibility to attentional biases based on previous experience and assumptions
- Susceptibility to environmental variations in temperature, sound, light, and time of day
- Degraded ability to sustain attention at night
- Susceptibility to extraneous factors such as personality, mood, and motivation

Perhaps the greatest weakness of the human detector is the susceptibility to extraneous factors such as personality, mood, motivation, the need for job satisfaction, and environmental impacts. As just one example, humans do not make good detectors at night, and it can be very difficult to overcome this inherent weakness. Human performance is also vulnerable to outside influences that can impact mood and motivation (e.g., disruptions at home may lead to performance degradations at work because the individual's mind is elsewhere). However, as pointed out earlier, strengths can become weaknesses, and human motivation can at times serve to overcome weaknesses.

In fact, Hancock (2013) argues that the vigilance decrement itself is actually a representation of the observer's adaptation to an enforced monitoring situation that has been poorly designed for sustaining attention. That is, rather than serving as a manifestation of an inherent human weakness, the typically observed degradation in performance over time is instead an adaptive adjustment to the situation that is encountered. Compelling people to perform a difficult watchkeeping task in which signals occur infrequently induces stress, which increases over the watch period. Without intrinsic motivation to perform the task, observers must adjust their observing responses to cope with the stress. This adaptation leads to the reduction in performance effectiveness known as the vigilance decrement. As Hancock (2013) points out, the problem is worse when the task involves monitoring automated equipment and displays that portray a representation of the target rather than the actual target itself. The manner in which that translation is accomplished can either facilitate or exacerbate vigilance performance. For more natural monitoring situations, such as those of a sentry on watch, the target can be directly perceived without this translational step. However, the task itself must still be properly designed to foster sustained attention (e.g., through appropriate work/rest schedules). According to Hancock (2013), *the vigilance decrement can be seen to reside as much in the way people encounter, organize, and convey work to the people who do it as it does in any intrinsic human failing*.

7.3. Human-System Integration Options for Vigilance Tasks

Human-system integration options for vigilance tasks revolve around deciding if, when, and how automated technology should be applied to assist or replace the human detector. *Automation* is any sensing, detection, information processing, decision making, or control action that could be performed by humans but is actually performed by machines (Moray, Inagaki, & Itoh, 2000). Automation is typically applied to replace human manual control, planning, and problem solving by automatic devices and computers, with the goals of increased efficiency, improved safety, enhanced flexibility of operations, and reduced operator workload. Although the aim in many cases is essentially to design unreliable and inefficient humans out of the system, even highly automated systems still need people for supervision, adjustment, maintenance, and improvement. As a result, both technical and human factors continue to be important because automated systems are still human-machine systems. Ironically, as control systems become more advanced, the role of the human operator may become even more critical. On the flip side, if automation is used to handle the "easy" parts of a task, the difficult aspects of the human operator's task may be made even more challenging in the process. As Bainbridge (1983) points out, system difficulties are not necessarily removed just by automating a process. Systems that are made less vulnerable to human error by incorporating automation become more vulnerable to designer error (Parasuraman & Riley, 1997). Ultimately, automation does not eliminate human error; it simply moves the locus of human error from the operator to the designer.

In fact, Parasuraman and Riley (1997) describe the phenomenon of *automation abuse*—inappropriate application of automation by designers or managers. Automation abuse occurs when designers decide to use technological innovations to replace human functions simply because they can. When this happens, the designers fail to adequately consider the consequences for human performance in the resulting system. As a result, the benefits anticipated by the use of automation may not be realized—overall system performance and operator workload may actually suffer because the human operator's capabilities and limitations have not been properly integrated into the system. Parasuraman and Riley (1997) caution that the operator's role should be defined on the basis of the operator's responsibilities and capabilities rather than as a by-product of how the automation is implemented.

When designing a system that involves vigilance tasks, the question is whether to use a human operator only, automated functions only, or some combination of the two. Automation does not have to be all-or-none. One model for human interaction with automation identifies types and levels of automation that then provide a framework and objective basis for deciding which system functions should be automated and to what extent (Parasuraman, Sheridan, & Wickens, 2000). The model identifies four broad classes of functions to which automation can be applied:

- Acquisition: information acquisition (sensory processing)
- Analysis: information analysis (perception and working memory)

- Decision: decision making
- Action: response

Within each class of functions, automation can be applied across a continuum of levels from low to high (i.e., from fully manual to fully automatic). Table 6 provides an example of a 10-point scale that can be used when considering various levels of automation during system design, primarily for decision making and responding (Parasuraman, Sheridan, & Wickens, 2000). The model extends these levels to cover automation for the input functions that precede decision making and action. For example, automation for information acquisition might consist of sensors to present environmental stimuli to the operator (low level), highlight potential areas of interest (moderate level), or actively filter information and present only the items of interest to the operator for viewing (high level).

Table 6. Levels of Automation

Level		Description
HIGH	10	The computer decides everything, acts autonomously, ignoring the human
	9	Informs the human if it, the computer, decides to
	8	Informs the human only if asked
	7	Executes automatically, then necessarily informs the human
	6	Allows the human a restricted time to veto before automatic execution
	5	Executes that suggestion if the human approves
	4	Suggests one alternative
	3	Narrows the selection down to a few
	2	The computer offers a complete set of decisions/action alternatives
LOW	1	The computer offers no assistance; humans must take all decisions and actions

Levels of automation can vary on a continuum from low to high for a given function within a system, and they can also vary at any point in time. The level of automation can even be designed to fluctuate, depending on the situation during operational use. This type of automation is known as *adaptive automation*. Under adaptive automation, an operator may actively control a process during periods of moderate workload, an automated system may take over this function during peak workload, and the operator may resume manual control when workload tapers off. In many situations involving adaptive automation, it is the automation that decides how to adapt to the human operator. Miller and Parasuraman (2007) argue that the human should always remain in charge, actively deciding how and when to use the automation to optimize task performance. That is, the human should be able to delegate tasks to the automation, in much the same way task delegation occurs in human-human work interactions. Miller and Parasuraman (2007) prefer the term *adaptable automation* to emphasize this difference in approach as compared to typical adaptive automation. The concept of adaptable automation conforms well to the factors important to pilots for effective human-automation interaction—pilots prefer to remain in charge of task allocation as well as the information presented (Miller, 1999). In effect, with adaptable automation, operators "finish the design" as needed at the time of execution, based on the situation at that point in time. Miller and Parasuraman (2007) describe a prototype implementation of adaptable automation for planning and commanding an unmanned air system mission. A series of studies conducted by the same researchers using a simplified delegation interface for a human-robot interaction task provided initial support for the concept of adaptable automation—mission success rates and mission completion times were superior under conditions of adaptable automation.

The critical consideration in deciding the type and level of automation during system design is evaluating the consequences for human operator performance in the resulting system after automation has been implemented. Automation can have both positive and negative effects on human performance, depending on how it is implemented. Common issues associated with automation are discussed in the next section.

7.3.1. Automation Issues

Automation can impart advantages in accuracy and speed that a human could not achieve alone. However, research has repeatedly demonstrated that use of automation can also have unexpected negative results, including loss of efficiency, performance, and safety (Parasuraman, 1987; Parasuraman & Riley, 1997; Sheridan, 1997). Automation does not merely replace the human. Instead, it changes human activity and can create new demands for coordination from the human operator. Common issues associated with automation concern operator trust, complacency, bias, skill degradation, and situational awareness.

7.3.1.1. Trust

Trust in automation has been defined on the basis of common elements in multiple definitions used throughout the literature (Lee & See, 2004). Trust is the *attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability*. One factor that impacts operator trust in an automated system, and therefore use of the system, is its reliability. Occasional failures of automation do not seem to deter future use of the automation. However, unreliable automation reduces operator trust and undermines potential benefits for system performance. An experiment involving automated fault diagnosis and management revealed that trust in automation was strongly affected by automation reliability (Moray, Inagaki, & Itoh, 2000). The system was trusted less as the reliability declined from 100% to 90% or 70%. Changes in reliability had a particularly strong effect below 90%.

Thus, trust is an attitude toward automation that affects reliance on the automation and subsequent use of the system. People tend to rely on automation they trust and reject automation they do not trust. Supporting appropriate trust is critical in avoiding misuse and disuse of automation. *Misuse* refers to failures that occur when people inadvertently violate critical assumptions and rely on automation inappropriately. Misuse can occur if trust exceeds system capabilities, leading to a condition of overtrust in which the system is not monitored closely enough. *Disuse* signifies failures that occur when people reject the capabilities of automation. Disuse occurs in conditions of undertrust in which trust falls short of the automation's capabilities (e.g., disabling or ignoring automated alarms). When undertrust occurs, the system is not used to its potential.

Mistrust of alerting systems is common in many work settings as a direct result of the false alarm problem. The decision threshold for the automated system is commonly set at a level so as to maximize correct detections, which frequently results in inordinately high false alarms. A low false alarm rate is necessary for human operator acceptance of alerting systems, as evidenced by incidents that have occurred because operators disabled or ignored alerting systems. For example, after the Conrail accident near Baltimore in 1987, investigators found that the alerting buzzer in the train cab had been taped over. Similarly, failure to detect a security breach at the Y-12 facility in 2012 was due in part to operators ignoring repeated alarm signals. One concept to mediate the false alarm problem is to use "likelihood alarms" instead to signify several possible levels of the condition being monitored, from very unlikely to very certain, rather than an all-or-none state.

A particularly important variable that interacts with trust to influence automation reliance is self-confidence. When operator confidence is high and trust in the system is low, operators are more inclined to rely on manual control. A study of a vehicle navigation aid found that system errors cause trust and reliance to decline more for those in a familiar city, whose self-confidence was high, as compared with those in an unfamiliar city, whose self-confidence was low (Kantowitz, Hanowski, & Kantowitz, 1997). Similarly, in a process control simulation, Lee and Moray (1994) found that participants opted for manual control if confidence in their own ability to control the plant surpassed their trust in the automation. Otherwise, they chose automation.

7.3.1.2. Complacency and Bias

Complacency and bias are two interrelated phenomena that can negatively impact performance with automation. Wiener (1981) defines complacency as a *psychological state characterized by a low index of suspicion*. Problems associated with complacency have been attributed to the tendency of human controllers to place too much trust in automated systems, allowing them to become absorbed in other tasks that require their attention and largely ignore the automated task. The potential for complacency has been found to depend on a person's trust in, reliance on, and confidence in automation (Singh, Molloy, & Parasuraman, 1993). Complacency is seen primarily in highly, but not perfectly, reliable environments in which the operator serves as a backup to the automation and endures some other condition such as high workload associated with performing many different functions concurrently. Given these conditions, the operator actively reallocates attention away from the automation in order to effectively perform other manual tasks, thereby missing failures of the automated system completely or responding more slowly. Operator complacency is troubling because it appears not to be mitigated by experience and practice (Parasuraman & Manzey, 2010). Further, complacency can limit overall system performance following a failure of the automation, even if the automation is very reliable.

Automation bias represents a case of inappropriate decision making linked to overreliance on automated decision aids. Alarm systems that alert operators to potential hazards represent the most basic example of automated decision aids. Such systems are intended to support information analysis and response selection by providing automatically generated cues to alert operators to changes in the situation that might require action or by providing recommendations for action. If automation bias is in effect, operators tend to view the automated aid as having greater power and authority than other sources of advice (e.g., other people). They place too much faith in the accuracy of the information presented by the automation than is warranted. As a result, operators use the decision aid as a replacement for active information seeking and processing. They may decide not to monitor the automation because they rely almost entirely on the automated decision aid to handle the situation. Decisions will therefore not be based on a thorough analysis of all available information, but will be strongly biased by the advice of the automated aid.

Evidence for automation bias has been obtained in aviation, health care, process control, and command and control (Parasuraman & Manzey, 2010). In aviation, for example, pilots who worked with a highly automated aid that specified and recommended a flight plan spent less time and effort generating and evaluating alternative plans than pilots working with a lower level of automation that provided only an evaluation of various plans for the pilots to review. In another situation, experienced commercial pilots who performed a simulated flight in a trainer equipped with an advanced cockpit automation system failed to detect 55% of automation failures (e.g., a heading change incorrectly executed by the flight system). These errors occurred despite the fact that the relevant information for an informed decision was available on various cockpit displays. In addition, the pilots exhibited extreme bias toward the automated aid in their response to an (incorrect) engine fire alert—100% of the pilots followed the input from the automated aid and shut down the engine, without checking other displays, gauges, or indicators.

The primary factors that influence automation bias are system properties and task context. In terms of system properties, automation bias depends on the level of automation present and the reliability of the automated aid. Automated aids that support only information integration and analysis, as opposed to specific recommendations for action, lead to lower automation bias effects. If recommendations are provided, one procedure to help combat automation bias is to supply system confidence ratings for each recommendation to help operators assess the validity of the recommendations. In terms of task context, operators who view themselves as accountable for the automated tasks tend to exhibit less automation bias, as evidenced by fewer errors when automation failures occur. Training and instruction, on the other hand, do not appear to impact the strength of automation bias.

A review of complacency and bias research led Parasuraman and Manzey (2010) to conclude that complacency and bias are actually related phenomena that reflect different aspects of the same kind of automation misuse. Namely, both complacency and bias stem from inappropriate reliance on automation, with attention constituting a central role in each case. Complacency is linked to reduced visual attention to the automated system stemming from an initial high level of trust in the automation and competition from other manual tasks that elevate the workload. Automation bias occurs when attentional resources are withdrawn from processing other available information in favor of the automated aid, under the assumption that the automation is all knowing and all powerful.

7.3.1.3. Skill Degradation

Loss of critical skills is a major concern with the introduction of automation since supervisory control replaces actual operation of the system. Personnel who function as supervisory controllers can become slower and more inefficient in bringing the system under control when a failure occurs as compared to those who operate the system in manual mode. Cognitive skills may also deteriorate with disuse. For example, effective retrieval of information from long-term memory depends on frequency of use. If the information is seldom used, it becomes increasingly difficult to retrieve when needed. For these reasons, flight crews often routinely operate in manual mode precisely to avoid the deterioration of skills that can occur with lack of use. Another option is to design the system for a moderate rather than a high level of automation to help operators retain the skills needed when the automation fails. A further concern is that appropriate skills may never develop if operators learn with automated systems from the beginning. Such skills may be important not only for manual task performance but also for the ability to detect the need for manual intervention.

7.3.1.4. Situational Awareness

Automation of decision-making functions may reduce operator awareness of the system and of certain dynamic features of the work environment. With such automation, the operator is not actively engaged in evaluating the information sources leading to the decision and therefore may not be able to maintain an accurate picture of the situation. Operator situational awareness commonly arises through a combination of three different processes (Endsley & Kiris, 1995):

- Perception of elements in the environment within a volume of time and space
- Comprehension of their meaning

- Projection of their status in the near future

Poor situational awareness can lead to what is known as the out-of-the-loop performance problem, whereby the operator's ability to take over manual operations if the automation fails becomes degraded. In an investigation of automobile navigation, low situational awareness corresponded with out-of-the-loop performance decrements in decision time following failure of an expert system for navigation (Endsley & Kiris, 1995). Operators were slower to perform the task manually following the breakdown than if they had been performing manually all along, and this effect was more severe under full versus partial automation. They also had poorer situational awareness when they had acted in a fully automatic condition versus the manual condition. This loss of situational awareness with increased levels of automation was attributed to a lack of active information processing. Passive processing of information in the fully automated condition degraded operator understanding of the situation around them. In a real-world example, the crash of Colgan Air Flight 3407 near Buffalo, New York, in 2009 was attributed to a lack of pilot situational awareness. Namely, the crew failed to adequately monitor flight instruments while operating in autopilot mode throughout the flight.

7.3.2. Automation for Sentry Duty

As in other domains, automated tools are becoming available to assist or even replace humans who perform sentry duty. The Mobile Detection Assessment and Response System (MDARS) is a joint Army-Navy program launched in 1993 to develop automated sentries to verify inventory, detect intruders, and check gates (Autonomous Robotics Programs, 2014). General Dynamics developed the MDARS robotic vehicles to detect walking, crawling, or running intruders at distances of approximately 300 feet. MDARS can complete patrol missions autonomously for up to 12 hours, randomly altering its path along the patrol, or it can be controlled remotely by a human operator at a workstation. Even if MDARS completes its mission autonomously, human operators are still needed to input the mission plan, monitor sensor and video feeds, and assess potential intrusions or suspect activity. Thus, humans are still necessary; they are just removed from the actual situation. Further, MDARS is designed to function as one component of a broader security system that includes fixed detection capabilities and human security guards. MDARS has been in limited use by the civilian operator guard force at Hawthorne Army Depot since 2004 and has been deployed at the Nevada National Security Site since 2010 for 24-hour security patrols. The Marine Corps also assessed the viability of MDARS for security and surveillance at Camp Wilson in Twentynine Palms, California, in January 2014. MDARS represents one automated option that might effectively supplement but not entirely replace human sentries.

Another system under development at the Defense Advanced Research Projects Agency (DARPA) is the Cognitive Technology Threat Warning System. The system uses a wide-angle camera and radar to collect imagery for a human operator to review on a computer screen. A wearable EEG device simultaneously measures brain activity and allows the system to detect brain waves signaling unconscious recognition of changes in a scene. In this way, events of interest can be detected without direct input from the human operator. Experiments in which participants reviewed footage shot at military test sites in desert and rain forest environments have demonstrated a system accuracy as high as 91% (for detection of critical events such as humans on foot or approaching vehicles). DARPA indicated that accuracy may be close to 100% if radar is incorporated. According to Devi Parikh of the Toyota Technological Institute at Chicago, the DARPA project *takes advantage of the human visual system without having the humans do any "work"* (Laursen, 2012). The primary disadvantage, of course, is that human operators become even more passive elements of the system since they must merely view the display in the system as currently configured. They have no decision-making or response responsibilities. Eventually, however, the system might be used in such a way to filter out the nonthreatening images and leave only the images that contain potential threats, based on the operator's brain wave activity, for the operator to actively review in depth.

If automation is to be used for sentry duty, the human weaknesses described in Section 7.2 highlight areas where automation might prove most useful (e.g., for nighttime vigilance tasks). However, as Hancock (2013) points out, regardless of whether automation is incorporated, the task must be properly designed to facilitate vigilance performance and not introduce another set of problems. The techniques listed in Section 8 of this report provide numerous options to properly design vigilance tasks that will rely on the human operator only. These techniques apply to the task of a sentry standing watch, with little more than eyes, ears, and a pair of binoculars to conduct the task. Performance in this type of situation may equal or exceed that of a system incorporating automated functions if the issues associated with vigilance performance are directly addressed, without introducing additional issues stemming from the use of automation.

The conclusion based on this review of the vigilance and automation literature is that the human sentry is a necessary component of an overall system that incorporates sentries at the front line (e.g., the site perimeter) as well as operators monitoring alarm displays at a remote location. The human sentry is needed at the front line to provide direct perception of potential intrusions. Monitors at a remote location provide an element of redundancy in the system to catch potential intrusions the sentry might miss due to vigilance issues. However, operators who monitor alarm displays may also suffer from poor vigilance. In addition, overall performance may actually be worse if such operators are relied on completely for intrusion detection because of the unique issues associated with automation (e.g., disabling or ignoring alarms).

Along these lines, investigation of the grounding of the cruise ship *Royal Majesty* off the coast of Nantucket, Massachusetts, in 1995 demonstrated the importance of maintaining purely visual watch (NTSB, 1997). The ship had an automated navigation aid based on GPS receiver output.

The GPS receiver was connected to an antenna mounted in an area of heavy foot traffic, which damaged the antenna cable and led to a loss of the GPS signal. Without a GPS signal, the automated navigation aid was unable to correct for prevailing tides and winds. As a result, the ship was gradually steered toward a sand bank in shallow waters. The NTSB report cited crew overreliance on the automated system and complacency associated with insufficient monitoring of other sources of navigational information, including radar and visual lookout. This incident implies the sentry continues to represent a critical element of the overall system—automation in and of itself is not a substitute.

8. TECHNIQUES TO IMPROVE VIGILANCE PERFORMANCE

The abundance of research in the field of vigilance provides an understanding of the factors that impact performance. In addition, such research provides the foundation to understand how observed performance deficiencies might be overcome. The following list provides a consolidated summary of recommendations to improve vigilance performance, categorized by the five primary factors that impact vigilance performance.

8.1. Psychophysical Manipulations

- Use auditory stimuli or provide both visual and auditory information
- Enhance the salience or duration of critical signals for detection so they are more easily differentiated from nonsignals
- Increase the signal rate during a vigil by inserting artificial targets for detection
- Combat the attentional biases that can occur to prevent observers from excluding areas of the display or field of view that tend not to be associated with target events

8.2. Task Modifications

- Provide standards for comparison to reduce reliance on working memory and make target/nontarget discriminations more simultaneous in nature
- Provide training with knowledge of results to help observers learn the subtleties that define how targets differ from nontargets
- Use a training task with a high signal probability to improve the efficiency of subsequent task performance
- When possible, provide knowledge of results periodically so observers can gauge how well they perform and whether their monitoring approaches work
- Use multiple observers to conduct a single monitoring task and combine their independent inputs to derive target/nontarget decisions, but be aware that a team setting may generate distractions if team member roles are not redundant.
- Consider performance incentives to improve detection efficiency, but develop an appropriate incentive that combats potential increases in false alarms

8.3. Environmental Modifications

- Prevent dynamic increases or decreases in body temperature (e.g., if the watch occurs outdoors, provide appropriately cooled or heated shelters for observers' rest breaks)
- Investigate the potential benefits of intermittent noise such as music

- Use shorter wavelength light around 470 nanometers and illumination levels in the range of 2000 to 4000 lux for optimal performance
- Recognize that the night shift is the worst time of day for vigilance performance and take extra measures to combat the deleterious effects
- Devise a schedule wherein observers spend no more than 30 minutes at a time on watch, alternated with five-minute rest periods or 30 minutes performing a different type of task (job rotation)
- Administer pleasant fragrances to maintain or restore alertness during a vigil, potentially at times when observers exhibit overt signs of fatigue or waning attention or provide fragrance-releasing devices that observers can activate on their own

8.4. Pharmacological Interventions

- Assess the feasibility of providing caffeine or chewing gum to boost overall performance efficiency and potentially moderate the vigilance decrement

8.5. Individual Differences

The primary recommendation to improve vigilance performance with respect to individual differences is to assign personnel who possess characteristics known to be associated with effective performance. These characteristics include:

- Introversion
- Field independence
- Internal locus of control
- Low proneness to boredom
- Low in cognitive failures such as lapses in attention
- High conscientiousness

Although research has demonstrated that the preceding characteristics tend to be associated with superior vigilance performance, the picture is far from complete. As early as the 1980s, Davies (1985) indicated that individual differences in vigilance performance are task-type specific. In addition, several recent studies have commented on the fact that traditional approaches for predicting vigilance performance or selecting the optimal observers do not appear to be working (Reinerman-Jones, Matthews, Langheim, & Warm, 2011; Teo, Szalma, & Schmidt, 2011). Namely, concentrating on unidimensional measures involving sensory acuity, aptitude, gender, age, and personality factors has not proven effective. Other possibilities need to be examined. Recommendations include studying both task properties and personal traits in combination for a full understanding of vigilance performance and adopting a theory-driven approach that considers different types of vigilance tasks and multidimensional predictors.

At this time, the best predictor of vigilance performance that has been identified is performance on a small sample of the task itself. For example, Matthews, Warm, Shaw, and Finomore (2010) used a 12-minute demanding vigilance task that presented stimuli at a rate of 60 events per minute. Performance on the short vigil was consistently correlated with performance on four different versions of a subsequent 60-minute vigil. Interestingly, in the visual inspection arena, a simplified version of the task itself is also considered the best predictor of inspection task performance (Gallwey, 1982).

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9. SUMMARY AND CONCLUSIONS

Scientific research of the human ability to sustain attention for prolonged periods of time began in World War II and continues to evolve as new and different types of monitoring situations arise. Such research has consistently demonstrated that correct detections of target stimuli decline as the vigil progresses (the *vigilance decrement*). Furthermore, vigilance or monitoring tasks are mentally demanding and stressful, imposing substantial demands on operators' information processing resources. The five primary categories of factors that impact vigilance performance include psychophysical parameters, task parameters, environmental parameters, pharmacological effects, and individual differences. Extensive research has revealed the impacts associated with each category that may degrade performance as well as the techniques that may be used in an attempt to improve vigilance performance. Of 12 major theories investigated for their ability to explain the results reported in the literature, a resource theory of vigilance currently offers the greatest explanatory value and provides a framework to guide future research. Further, recent research efforts show promise in developing techniques to predict vigilance performance and select the optimal observers for the task.

Sentry duty is one type of real-world vigilance task that requires observers to maintain attention for prolonged periods of time in order to detect infrequently occurring target events. The sentry typically functions as part of an overall system that includes alarm displays monitored by personnel at remote locations. Recent developments in automation suggest that it may be possible one day to replace the human sentry entirely with automated devices. The conclusion in this paper, however, is that the human sentry is a necessary component of a broader system that incorporates sentries at the front line (e.g., the site perimeter) as well as operators at remote location monitoring alarm displays. Human sentries are especially valuable in cases where technology provides a poor substitute for human capabilities (e.g., some objects cannot be detected by radar) or where technology fails altogether. Regardless of whether automation is incorporated or not, the vigilance task must be properly designed up front to optimize system performance.

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