Methods For Mitigating The Vigilance Decrement In An Auditory Sonar Monitoring Task: A Research Synthesis

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ABSTRACT

Sustained attention or operator vigilance is required in the detection of critical signals that occur infrequently and at irregular intervals over a prolonged period. In this paper, we review some methods for mitigating the vigilance decrement for an auditory sonar monitoring task. These methods pertain to enhancing the saliency of sonar targets for situations when the operator may be required to monitor multiple displays, listen to competing sound sources, attend to distractions, and cope with ambient noise. Enhanced target saliency is expected to assist in maintaining operator efficiency via increasing detection rate and decreasing detection latency of auditory sonar targets. This should lead to tactical superiority of sonar operators in the continuing threat of underwater warfare.

SOMMAIRE

Il est nécessaire que l'opérateur fasse preuve d'une attention ou d'une vigilance soutenues pour détecter les signaux critiques qui se produisent peu fréquemment et à des intervalles irréguliers sur une période prolongée. Le présent document examine certaines des méthodes permettant d'atténuer la baisse de vigilance durant une tâche auditive de surveillance sonar. Ces méthodes mettent en évidence des cibles sonar dans des situations où l'opérateur doit surveiller plusieurs affichages et prêter l'oreille à des sources sonores conflictuelles alors qu'il est exposé à des distractions et à du bruit ambiant. La mise en évidence des cibles devrait aider à maintenir l'efficacité de l'opérateur en augmentant le taux de détection et en diminuant la latence de détection des cibles sonar durant une tâche auditive. Il devrait en résulter une supériorité tactique de l'opérateur sonar dans la menace permanente de la guerre sous-marine.

1. INTRODUCTION

Submarine warfare continues to pose a threat in present-day military operations. This prompted the Canadian Forces (CF) to research and develop sonar systems in an effort to increase the probability of enemy detection (Theriault & Chapman, 2001). Despite the ongoing technological improvements made to sonar systems, the human operator remains as an integral component in sonar watchkeeping. To this end, we initiated a research project within Defence R&D Canada (DRDC) – Toronto to investigate techniques for maintaining operator vigilance or sustained attention. Our synthesis of the literature on vigilance forms the basis of the present paper.

Operator vigilance is required in the detection of critical signals that occur infrequently and at irregular intervals over an extended period of time (e.g., detecting targets in military surveillance devices, airport security inspection of x-rayed carry-on luggage, industrial inspection of products, and monitoring of automated systems).

Undoubtedly, the failure to detect targets for real-world applications could have severe consequences. The laboratory study of vigilance, dating back to World War II, was prompted by the British military's need to understand the decline in performance of airborne radar operators engaged in antisubmarine warfare who missed blips on the plan position indicator radar screen after only about 30 minutes on watch. N.H. Mackworth (1950) was commissioned by the Royal Air Force in 1948 to address the observed decline in radar operator performance. He devised the "Clock Test" which consists of a single rotating black pointer on a white background. The pointer moved clockwise to the next position once every second. Occasionally, however, the pointer "jumped" twice the normal distance. The "double jump" of the pointer was the target, and the participant's task was to indicate when he/she detected its occurrence. Twelve targets had to be detected per 30 minute period of the 2-hour watch, appearing at intervals from 45 seconds to 10 minutes. Detection efficiency, as measured by number of missed targets, deteriorated rapidly after the first 30 minutes which confirmed the results of the analysis of detections from real radar operations. The failure to detect targets is not restricted to the visual modality. In a separate experiment, Mackworth (1950) found that the incidents of missed targets for an auditory task also increased as a function of time on task.

Following Mackworth's (1950) pioneering studies, investigations on factors that affect operator attentiveness for the detection of critical signals have been conducted using a myriad of experimental paradigms and performance measures (for reviews see Ballard, 1996; Davies & Parasuraman, 1982; See, Howe, Warm, & Dember, 1995; Warm, 1984, 1993). The results of these studies have generally confirmed Mackworth's observation of a decline in observer performance (called the "vigilance decrement") over time (referred to as the "watch"). A view held for many years was that the decrement could be attributed to signal detection theory (SDT) measures of the user's sensitivity (d′) and the user's own criterion (β) (Green & Swets, 1966; Macmillan & Creelman, 1991) whereby a drop in arousal can cause a decrease in d' as to the presence of the target or a shift in β (more or less conservative criterion) as to what sensory inputs constitute a target (Davies & Parasuraman, 1982; Warm, 1984). However, recent evidence suggests the alternative explanation that the information processing demand of a vigilance task is high and the decrement reflects the depletion of information-processing resources over time (Helton et al., 2005; Johnson & Proctor, 2004; Warm & Dember, 1998; Warm, Dember, & Hancock, 1996). Warm et al. (1996), for example, found that ratings of mental demand increased linearly over the course of the vigil as measured by the NASA-TLX index – an instrument used to measure perceived mental workload on the processing resources imposed by a task (Hart & Staveland, 1988).

The results of laboratory studies on vigilance research have shown that techniques can be applied to mitigate the vigilance decrement (e.g., Baker, 1962; Jerison, 1967; Schmidke, 1976). The validity of these results depends upon the successful transfer of laboratory results to real-world applications. To date, there are only a few published studies relating to the application of laboratory research findings for maintaining operator performance or efficiency in real-world tasks. Investigators have observed a decline in vigilance in tasks such as detection of aircraft entering designated air space (Pigeau, Angus, O'Neill, & Mack, 1995), monitoring sonar signals (Colquhoun, 1967, 1975, 1977), and keeping watch for automation failure in a flight simulation task (Molloy & Parasuraman, 1996). The decrease in operator performance noted in operational tasks requires that techniques be developed for maintaining alertness. One method that has been shown to maintain or improve user efficiency is an increase in the saliency of the target (Colquhoun, 1967; Lisper, Kjellberg, & Melin, 1972). Weak targets, such as those found in a real-world sonar environment, may go undetected by the operator. This may compromise tactical superiority in submarine warfare (Arrabito, Cooke, & McFadden, 2005). Enhancing the saliency of targets is expected to make more targets perceptible to the operator. This should lead to maintained or enhanced performance as reflected by an increase in detection rate, a decrease in the number of false alarms and incidents of missed targets, and a faster response time to targets that are correctly detected. The objective of the present paper is to discuss methods for enhancing the saliency of aural sonar targets.

2. THE SONAR ENVIRONMENT

The sonar operator, either on board an aircraft (fixed or rotary wing) or a vessel (surface ship or submarine), is responsible for accurately detecting the presence and determining the position of targets (e.g., surface ships, submarines, torpedoes, and mines) to allow for effective weapon deployment. Sounds received at the hydrophone (an underwater microphone) of the sonar systems are initially processed to help make the signals perceptible to the human observer, and these data are presented on a visual and/or auditory display (Urick, 1983). Aural signals are usually presented over headphones, especially in a noisy environment (e.g., in aircraft or in the Operations room of a vessel containing multiple sonar consoles). The operator must monitor the display and report when he/she detects the target. The acoustic characteristics of targets are generally unknown because recordings of sonar signals are typically produced by military organizations and often these become classified. Operators evaluate the aural characteristics of sonar sounds within a frame of reference or vocabulary (e.g., "heavy", "light", "bright", "dull", "hard", and "soft") and judge them as either a target or non-target (Collier, 2004; Solomon, 1958). In practice, the operator attempts to get multiple readings on an object over time in an effort to ensure high accuracy. Data on sonar detection performance is not available. Once a target is detected, the operator will determine its position and attempt to classify and track the source. The watchstanding period is typically between 2-3 hours on helicopters, 4-8 hours on fixed wing aircraft, and 8-12 hours on vessels (Arrabito et al., 2005). Rest periods are given when possible, and are often dictated by operational requirements.

Sonar systems can generally be categorized as passive (listening) or active (echo ranging). A passive sonar system is designed to detect the noise radiated by a target and received at the hydrophone(s). An active sonar system emits a short duration acoustic pulse that is propagated in the water towards the desired target. There are two broad classes of pulses: coherent and incoherent sources (Le Méhauté & Wang, 1996; Urick, 1983). The choice of pulse type is application specific (Horton, 1957; Le Méhauté & Wang, 1996; Waite, 2002). The returned signal from the pulse received at the hydrophone array contains one or more echoes. The echo is the acoustic energy that is reflected from the target. The echo is only a fraction of the acoustic energy of the transmitted pulse and can often be obscured by reverberation which is the acoustic energy reflected from sources other than the desired target. The received echo is the bearing (i.e., co-ordinates) of the target. The range (i.e., distance) of the target is calculated by taking into account the non-homogeneity of the ocean environment (due to the water varying in density, temperature, and salinity that can distort the sound), and the time between the offset of the transmitted pulse and the reception of the echo. The hydrophones are generally configured in an array (examples of array types include a line, broadside, shaded, planar, cylindrical, conformal, spherical, and volumetric (Waite, 2002)) in order to improve the signal-to-noise ratio (SNR) of the source against a noise background. Some examples of sonar systems are shown in Figure 1. The choice of sonar system is a function of the current tactics.

Having superior sonar equipment is by no means a suf-

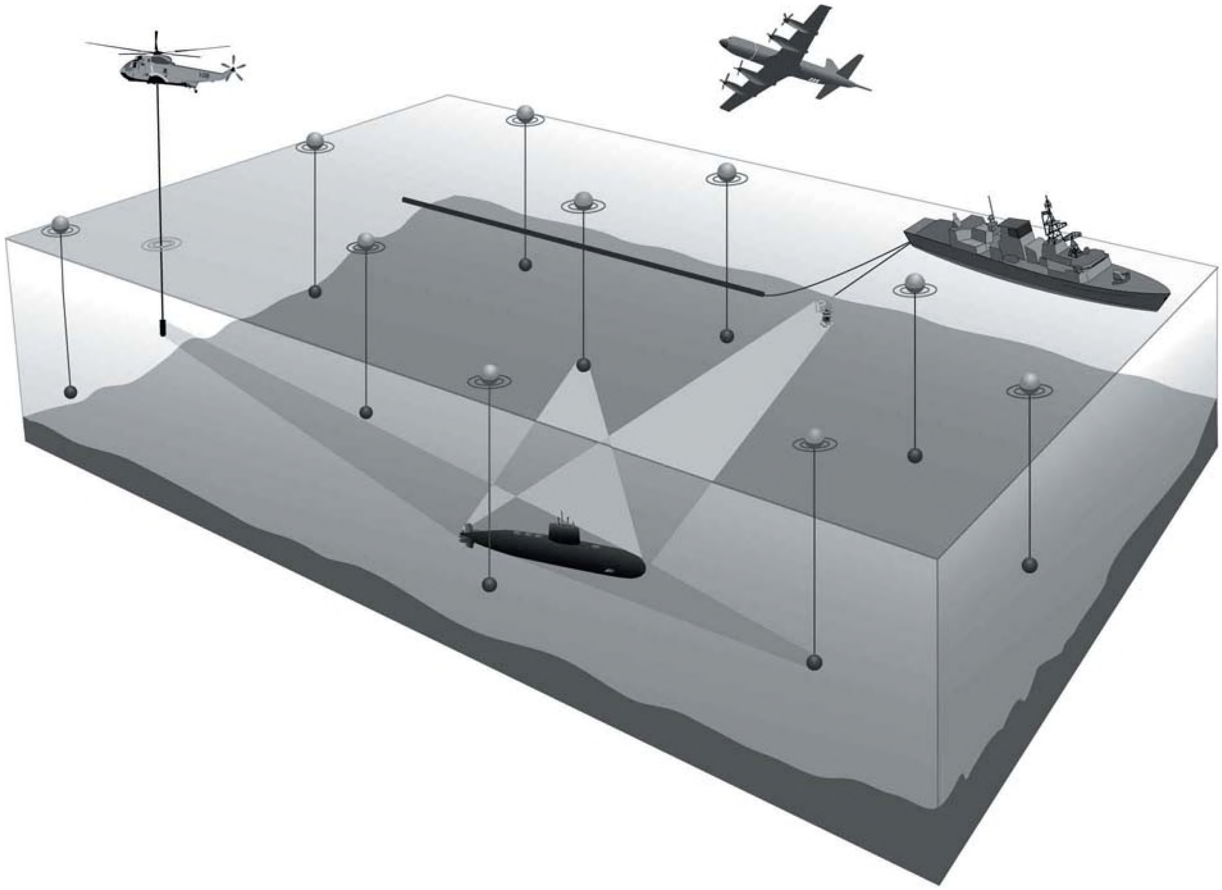

Figure 1: Some examples of sonar systems. The surface ship is towing two different arrays, a long passive array and an active multistatic array. The airplane has deployed ten sonabuoys (often shortened to "buoys") in a predefined pattern; each buoy has a hydrophone and a radio transmitter. Data from the buoys are radioed to the aircraft for processing, and displayed to the operator for interpretation. A dipping sonar system is employed by the helicopter. Although not illustrated in this figure, a vessel (surface ship or submarine) could also employ a hull-mounted sonar system which is located on the hull of the vessel (usually on the keel). The figure illustrates how the different sonar systems can be used to detect an underwater or surface target. Courtesy of Neil Sponagle, Defence R&D Canada – Atlantic.

ficient condition for achieving success in a mission. Often many factors can influence the performance of the sonar operator in the task of detecting and classifying targets. These include sound travel in water (e.g., foreign objects, absorption, scattering, reflection, and reverberation), environmental factors (e.g., time of day, weather, season, ambient noise, water depth, and salinity), own ship performance (e.g., ship and sonar design, speed, and self noise), target strength (e.g., target design, signature and speed), and operator conditions (e.g., doctrinal practices, operator experience and intuition, motivation and alertness) (Cox, 1974; Horton, 1957; Moore & Compton-Hall, 1986; Urick, 1982). The variability of the tactical environment contributes to the difficulty of detecting and classifying targets (Cox, 1974; Moore & Compton-Hall, 1986). Once the target is detected and classified, a variety of weapons (e.g., missile, torpedo, and mine) could be deployed (Moore & Compton-Hall, 1986). Targets in turn can utilize countermeasures, such as maneuvering or deploying devices, to reduce the success of an attack (Cox, 1974; Moore & Compton-Hall, 1986).

3. SOME METHODS FOR COMBATING THE VIGILANCE DECREMENT

The application of SDT (Green & Swets, 1966; Macmillan & Creelman, 1991) to the analyses of vigilance tasks was first proposed by Egan, Greenberg, and Schulman (1961). This represented a major advance in the assessment of user efficiency. SDT takes into account false alarm rates which were not done in early studies of vigilance. In this section, we list some countermeasures for altering d' (by manipulating sensory parameters), and β (by manipulating nonsensory parameters) that could help attenuate the decrement for an auditory sonar monitoring task. For a more detailed discussion of these countermeasures, the reader is referred to Davies and Parasuraman (1982), and Matthews, Davies, Westerman, & Stammers (2000). We note that these techniques have been explored in controlled laboratory experiments and thus their applicability to operational scenarios has yet to be determined.

3.1. Techniques to Increase d'

- Decrease the event rate (i.e., rate of presentation of non-targets) (Jerison & Picket, 1964; Loeb & Binford, 1968). In an operational setting, unwanted events are usually more frequent than targets. Jerison and Picket (1964) were the first to show that an increase in event rate for a visual vigilance task lead to a decrease in detection rate and an increase in missed targets.
- Increase the probability of target occurrence (i.e., the ratio of target to non-targets) (Colquhoun, 1961). In a visual vigilance task, Colquhoun (1961) varied signal frequency and target probability independently. He found that an increase in target probability improved detection efficiency but a similar increase in signal frequency produced no significant alteration in detection efficiency.
- Enhance the saliency of the target (e.g., by prolonging the duration or increasing the intensity) relative to non-targets (Colquhoun, 1967; Lisper et al., 1972). The detection of stimuli is positively related to increases in signal saliency. Lisper et al. (1972) investigated the effect of signal intensity response time on an auditory monitoring task. Participants were instructed to respond as quickly as possible when they heard the target which was presented at four different signal intensities. The results showed that speed and accuracy increased as a function of increasing signal intensity.
- Give the user extensive practice (Colquhoun, 1975; Colquhoun & Baddeley, 1967). Colquhoun and Baddeley (1967) varied signal probability during pretraining in an auditory vigilance task. The authors found that practice increased overall number of signals detected but that higher signal probability lead to an increase in false alarms.
- Inject artificial signals that closely resemble the target (Mackie, Wylie, & Smith, 1994). Mackie et al. (1994) observed enhanced operator vigilance when signal injection was provided in a task that required participants to detect passive sonar targets presented on a visual display. Enhanced operator performance was reflected by increased target detection and decreased latency times in the detection of the targets.
- Present varied noise at a low sound level provided that the vigilance task is not complex (Hancock, 1984; Matthews et al., 2000; Nachreiner & Hanecke, 1992). Such results are dependent in part upon task difficulty, the state of the individual, and the ability of the individual to learn how to perform the task in quiet and in a background of noise.

3.2. Techniques to Optimize β

- Instructions favoring risk in responding to the presence of the target (Colquhoun, 1967). Colquhoun (1967) used a simulated auditory sonar task in which participants were instructed to adopt two strategies for determining the occurrence of a target. In four of the eight sessions, participants were instructed to report the presence of the target when they were absolutely certain they had detected the target ("sure condition). In the other four sessions participants were instructed to report any target-like signal ("unsure" condition). There was a substantially a higher percentage of signals detected in the "unsure" condition than in the "sure" condition.
- Provide the user with performance feedback or knowledge of results (Mackworth, 1950; Wiener, 1963). Performance efficiency can be substantially improved by providing feedback or knowledge of results (KR) to the observer. Wiener (1962) investigated varying levels of KR in a visual monitoring task. He found that mean probability of detection increased as a function of increasing KR. False alarms were higher with partial KR than with either full KR or no KR.
- Include periodic breaks throughout time on task (Davies & Parasuraman, 1982; Mackworth, 1950). Rest periods or assigning another activity can have beneficial effects on monitoring performance. Mackworth (1950) recommended that the break should occur within the first 30 minutes of the watch.
- Employ methods to motivate the user (e.g., participants' knowledge of the presence of the experimenter in the test facility, and periodic encouragement) (Fraser, 1953; Mackworth, 1950). Fraser (1953) used a modified version of Mackworth's (1950) clock test. Participants were tested with and without the presence of the experimenter in the laboratory. Fraser (1953) found that the presence of the experimenter improved performance.

4. THE SONAR VIGILANCE TASK

Monitoring for the appearance of critical signals is generally categorized as either a successive discrimination or a simultaneous discrimination vigilance task. Of these two paradigms, the monitoring for sonar targets could be classified as a successive discrimination task. In a successive discrimination task, the observer must remember the stimulus configuration of the target (i.e., signature of the sonar target) and subsequently compare the remembered signature against successively presented non-targets (e.g., a 2 dB increase in the intensity [target] of an intermittent 1000 Hz tone). In contrast, in a simultaneous vigilance task, the stimulus configuration of the target is present, and the observer has all the required information to make the discrimination between target and non-target (e.g., to detect a 1000 Hz tone [target] within an intermittent noise burst) (Parasuraman, 1979). Davies and Parasuraman (1982) have argued that a successive discrimination vigilance task is more capacity demanding than a simultaneous vigilance task. To test the validity of the taxonomy developed by Parasuraman and Davies (1977) for classifying task according to type of discrimination, See et al. (1995) conducted a meta-analysis of the sensitivity decrement based on 42 experiments published between 1980 and 1992 and confirmed that the sensitivity decrement in vigilance are linked to task differences. For example, increases in event rate had a more degrading effect on user performance for a successive than a simultaneous vigilance task (Lanzetta, Dember, Warm, & Berch, 1987).

In the context of an auditory sonar vigilance task, the decrement could arise from various factors that deplete the availability of information processing resources during the vigil. Generally, there is a low target rate (Mackworth, 1957) and long intervals of time (in the order of days or weeks) pass without a single target occurring (Mackie et al., 1994). The occurrence of critical signals at irregular intervals in time forces the observer to monitor the display continuously. This adds to task demand and has been shown to further degrade performance efficiency than when critical signals are presented at regular intervals. This effect is greater for a successive than a simultaneous discrimination vigilance task (Davies & Parasuraman, 1982; Helton et al., 2005; Warm & Jerison, 1984).

A smaller degradation in performance is expected in an auditory sonar watchkeeping task than its visual counterpart because the critical signals may be perceived aurally even when the operator's eyes are directed elsewhere (referred to as decoupling (Warm & Jerison, 1984)). Unlike an auditory display, the use of a visual display imposes postural constraint, and eye strain. To elucidate the differences across modalities, Szalma et al. (2004) equated auditory and visual vigilance tasks in discrimination difficulty and found that performance deteriorated with time-on-task, and that the auditory modality was superior to the visual modality; these results are in general agreement with previous findings (Davies & Parasuraman, 1982; Warm & Jerison, 1984). Szalma et al (2004) attributed the superiority of the auditory modality to the decoupling nature of visual displays which imposes task demand on a visual vigilance task (Galinsky, Rosa, Warm, & Dember, 1993).

Often the operator is unaware of the signature of a sonar target because targets may be camouflaged, muffled, or distorted due to the non-homogeneity of the ocean environment. Previous studies have shown that in instances where the target was not specified, participants had a lower percent correct and higher false alarm rate than when they were specified (Childs, 1976). Notwithstanding target specification, detection of sonar targets may be made more difficult if the level of the sound received by the hydrophone is too low relative to the level of the background noise (i.e., low SNR). The problem may be further exacerbated if the level of the target is close to the operator's threshold of audibility or if the target is a transient sound (e.g., hull popping that could be caused by a submarine changing depth, engine start-up sequences, and squeaks that could be caused by rudder motion). These factors relate to target saliency. We now propose some techniques to increase signal saliency which will decrease task difficulty (Davies & Parasuraman, 1982; Matthews et al., 2000).

5. METHODS FOR INCREASING SIGNAL SALIENCY FOR AN AUDITORY SONAR MONITORING TASK

Enhancing signal saliency, a technique used to increase sensitivity, was shown to mitigate the vigilance decrement for a simulated auditory sonar monitoring task (Colquhoun, 1967). In previous laboratory studies, the saliency of the target was enhanced simply by raising the intensity of the signal in relation to the background noise (Colquhoun, 1967; Lisper et al., 1972). However, this tactic may not always improve target detection because, for example, the overall sound level may become too loud, potentially leading to temporary or permanent hearing loss or interference with concomitant communication tasks. In this section we review some psychoacoustic methods for increasing the saliency of aural targets that could be applied to sonar watchkeeping, when the operator is required to monitor multiple displays, attend to distractions, and cope with ambient noise.

5.1. Sensory Modality

The probability of correctly detecting the target will be highest if the target is presented in the sensory modality best suited for eliciting the user's attention in the underlying monitoring task. Whilst a visual display may be effective for detecting narrowband sounds on passive sonar displays and for long range detection of targets, the visual modality is dependent of the direction of the operator's eyes and thus is not optimal for the detection of transient sounds. Transient sounds are difficult to disguise and can often alert the sonar operator to the presence of a target or signal a state change of the target being tracked. The aural presentation of these signals would lead to a greater probability of detection as the human auditory system excels in the detection of transient signals in the presence of noise (Moore, 1989). Sensory differences have also been found for visual and auditory vigilance tasks. The overall level of performance in auditory vigilance tasks tends to be greater than visual tasks, and the vigilance decrement is less pronounced in the auditory than in the visual modality (Davies & Parasuraman, 1982; Warm & Jerison, 1984; Szalma et al., 2004).

5.2. Competing Sound Sources

Competing sound sources could lower the probability of successful target detection. This is particularly difficult when the operator must detect the target in the presence of competing signals (e.g., speech). This is analogous to the "cocktail-party problem" (Cherry, 1953). Cherry (1953) investigated the listener's ability to focus his/her attention on a single sound source or signal in the presence of multiple competing signals and interfering noise. He suggested that the cocktail party problem could be solved primarily by spatially separating the sound sources. Spatial separation between signals for a sonar application could be realized over headphones via three-dimensional (3-D) auditory space (a technique to present sound over headphones that is convolved by means of a digital filter is perceived by the listener to emanate from outside his/her head at the location for which the digital filter was measured (Bronkhorst, 1995; Wightman & Kistler, 1989)). Ericson and McKinley (1997) investigated the viability of a 3-D audio display for solving the cocktail party effect. These authors reported improved speech intelligibility when more than two simultaneous talkers were each spatialized at unique positions in virtual auditory space compared to a diotic presentation of the talkers (i.e., same signal to each ear). The application of spatial auditory cueing for aviation tasks involving target detection/acquisition enhanced performance efficiency (Gunn, Warm, Nelson, Bolia, Schumsky & Corcoran, 2005; Tannen, Nelson, Bolia, Warm & Dember, 2004). These results suggest that spatial cueing could also augment performance in a sonar vigilance task where the operator is listening to competing sound sources.

5.3. Ambient Noise

The airborne sonar operator is usually exposed to high levels of ambient noise in the cockpit (Rood & James, 1999). From an operational perspective, high levels of ambient noise can impair monitoring efficiency in the detection of sonar targets. For example, the detection of low-frequency sonar targets could go unheard (i.e., masked) if they are near the dominant frequency region of the ambient noise source. Lowering the at-ear sound level of the ambient noise will increase the SNR of sonar targets that could lead to enhanced signal saliency. This can be achieved by using conventional or active noise reduction (ANR) hearing protection incorporated in the headset worn by the operator. Further enhancement may be achieved by integrating ANR and 3-D audio technologies, as proposed by Giguère, Abel & Arrabito (2000). Lower sound levels can extend the operator's exposure time to intense sounds (Moore, 1989) which could improve operator comfort and efficiency (e.g., earlier or more reliable target detection), predominantly when conducting long patrols.

5.4. Auditory Distractions

While monitoring sonar signals, a distracting event such as an auditory alarm (i.e., a signal intended to alert operators to the presence of a potential emergency) requires the operator to focus his/her attention to this new situation. The reallocation of attention to the distracting event could potentially lead to incidence of missed targets. The goal, therefore, is to minimize resources required to address the distracting event. Accurate encoding of urgency in auditory alarms through effective use of physical characteristics of the sound such as frequency composition, repetition rate, amplitude, and harmonic relation of the frequency components (e.g., Edworthy, Loxley, & Dennis, 1991; Hellier, Edworthy, & Dennis, 1993) may both increase the detectability and reduce the time required to address the alarmed condition without adding to workload (Haas & Casali, 1995; Sorkin, 1988). As the result, the disruption on operator efficiency when monitoring for sonar targets should be minimized.

5.5. Dual-Mode Displays

Sonar signals are presented either in the visual or auditory modality but rarely in both modalities simultaneously (known as a dual-mode display). Dual-mode displays have been evaluated for the detection and classification of simulated passive sonar signals (Colquhoun, 1975; Doll & Hanna, 1989; Kobus et al., 1986; Lewandowski & Kobus, 1989). A bimodal display has generally led to improve target detection and classification (Colquhoun, 1975; Doll & Hanna, 1989; Kobus et al., 1986; Lewandowski and Kobus, 1989). However, Kobus et al. (1986) did not show a statistically significant advantage for a bimodal display compared to the single best modality. The authors attributed their findings to the large differences in the spectral characteristics between the sonar targets.

6. IMPLEMENTATION CONSIDERATIONS

While the foregoing discussion on proposed methods for enhancing the saliency of aural signals are effective for increasing target detection, their utility in the vigilance domain for a real-world auditory sonar monitoring task has yet to be evaluated. We believe that the proposed methods could be implemented on most sonar systems. User performance for the detection of sonar targets should increase even further when the proposed methods are incorporated in conjunction with other countermeasures known for mitigating the vigilance decrement (Davies & Parasuraman, 1982; See et al., 1995; Warm, 1984, 1993). However, as sonar monitoring typically has a low event rate, special care is required for the development of training methods for tasks that have a low probability of occurrence of critical signals (Parasuraman, 1986). Other counter-measures such as injection of artificial signals may not be practical to employ in present-day sonar systems due to factors such as hardware limitations or cost. Hence, the viability of any countermeasure for a real-world sonar task remains the subject matter of future investigation.

Assessing the benefits of enhanced target saliency in a real-world sonar monitoring task may not be possible. As pointed out by Parasuraman (1986), the vigilance decrement is not the sole indicator of operator deficiency in a vigilance task. In operational tasks, the level of vigilance performance may be below a preset standard of performance, regardless of the decline in efficiency associated with time-on-task. For an operational sonar task, the calculation of the minimum level of efficiency is not practical due to the covert nature of the sonar environment. Upholding a preset minimum standard of user efficiency by employing methods to motivate the sonar operator (Fraser, 1953; Mackworth, 1950) would not suffice. The resource depletion alternative to the arousal model of the vigilance decrement (Helton et al., 2005; Johnson & Proctor, 2004; Warm & Dember, 1998; Warm et al., 1996) is important not only on a theoretical level but also on a practical level. Supervisors in the operational environment intuitively believe that the failure of target detection in vigilance results from the operator not monitoring the display because he/she was not attentive. If the decrement is to be modified in a sonar operational setting, supervisors must understand that the decrement may not be the result of lack of effort, but rather of resource depletion based upon task engagement. Recent studies using transcranial Doppler sonography (TCD), a non-invasive neuroimaging technique that employs ultrasound signals to monitor cerebral blood flow velocity (CBFV), provide additional support for the resource depletion model (for a review, see Warm & Parasuraman, 2007). These studies have revealed a corresponding decline in blood flow and user performance over the course of the vigil, and they provide empirical support for the notion that blood flow may represent a metabolic index of information processing resource utilization during sustained attention. A decline in CBFV occurs in comparable visual and auditory vigilance tasks (Shaw et al., 2006). TCD may offer a noninvasive and inexpensive tool to "monitor the monitor" and to help decide when operator vigilance has reached a point where task aiding is necessary or operators need to be given breaks or removed (Warm & Parasuraman, 2007). We predict that enhanced target saliency may help reduce resource depletion.

7. CONCLUSIONS

The existence of a decline in operator efficiency has been observed for some real-world monitoring tasks. Whether the decrement for the monitoring of aural sonar targets is as pervasive as those reported in laboratory studies requires further investigation. The practical implications of enhanced target saliency are an increase in the detection rate and potentially shorter latencies in the detection of targets. The financial cost of implementing the proposed methods should be offset by an expected increase in operator performance, potentially leading to tactical superiority in the continuing threat of underwater warfare.

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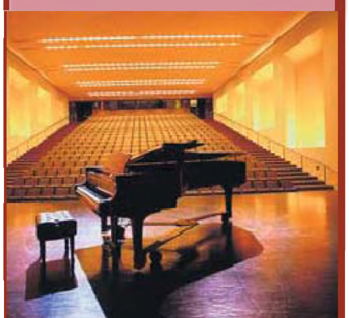


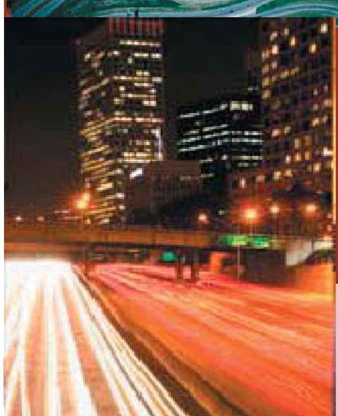

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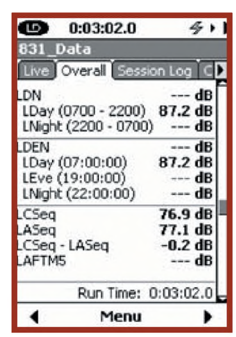

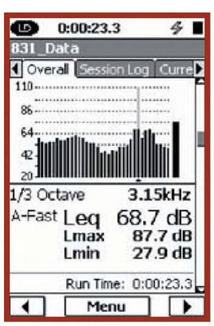

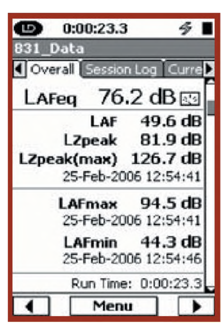

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