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THEORETICAL EXPLANATION OF VIGILANCE DECREMENT

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ABSTRACT

Vigilance refers to the ability to remain alert on a specific task for longer period of time. During vigilance task performance usually declined with increase in time which is termed as vigilance decrement. Present paper discusses about numerous theories that have been proposed to explain vigilance performance. However, yet a theory has to emerge that could make specific performace related predictions. Recently, two broad families of theories of failures of sustained attention are widely debated in the literature. The first family of theories contends that the decrement in vigilance performance occurs due to mindlessness, boredom, or cognitive under-load produced by monotonous nature of vigilance tasks. On the contrary, the second family of theories posits that the vigilance decrement occurs due to resource demand, mental fatigue, or cognitive over-load placed by highly demanding nature of vigilance tasks.

Keywords: Vigilance, Vigilance decrement, Mindlessness, Mindfulness.

INTRODUCTION

Vigilance is the ability of individuals to sustain their focus of attention to the stimuli over prolonged periods of time. The vigilance occupies a unique niche in psychology and is a sort of problem that accommodates both basic researches and more applied interests. The capacity to sustain attention during the activities of the daily life is essential for our perceptual functioning and also is a fundamental element in behavioural adaptation.

Norman H. Mackworth was the first who conducted a series of systematic and ingenious controlled

laboratory research on sustained attention and pointed out the theoretical as well as the practical implications of watch-keeping behavior (Davies & Tune, 1969) which provided several fundamental findings and set the tone for much of the work to follow. Mackworth borrowed the term vigilance from Sir Henry Head to describe the watchkeeping behavior or monitoring tasks. Mackworth used the term to characterize an observer's ability to detect and respond to small stimulus changes in situations in which one must direct attention to sources of stimulation for long, unbroken periods of time (Davies & Parasuraman, 1982). Machworth devised a stimulated radar display called the clock test in which subjects were asked to view movement of a black pointer along the circumference of a blank-faced clock which contained no reference points. Once every second, the pointer would move 0.3 inch to a new position. From time to time, it executed a 'double jump' of 0.6 inch, and this was the critical signal for detection onto which a key press was required. The entire session lasted for 2 hours. Mackworth developed the chart of course of performance over time and confirmed that the quality of sustained attention in monitoring tasks wanes rapidly. The progressive declines in performance with time on task were also found in a large number of subsequent investigations. This progressive decline in performance has been termed the decrement function (Dember & Warm, 1979) or the vigilance decrement (Davies & Parasuraman, 1982). Studies suggest that the vigilance decrement is complete within 20-35 minutes after the initiation of the vigil and at least half of the final loss is completed within the first 15 minutes (Teichener, 1974).

Mechanism of Vigilance: Theoretical Framework

Since Mackworth's experiments (1948, 1950), various theories have been developed to elucidate vigilance behaviour. However, most theories of vigilance are devoted exclusively in finding the probable sources of decline in performance during vigilance task rather than focusing on the overall performance. These theories may be classified broadly under three different models: (a) learning models; (b) neurological models; (c) information processing models.

Learning Models include inhibition theory and observing responses. Like the first systematic study in the field of vigilance, the first theory of vigilance decrement was proposed by Mackworth (1950) in the form of Inhibition theory which were based on the findings of his clock test. During the demonstration period of clock test the subjects responded whenever the experimenter signaled him. The signal comment by experimenter was usually delivered upon the occurrence of double jump, thus, the signal comment became the unconditional stimulus while, the double jump of clock hand became the conditional stimulus and the conditioned response was the key pressing. Mackworth explained the vigilance decrement with classical conditioning and the corresponding extinction process. The training period, when the experimenter reinforces correct detections, was considered the conditioning period. The two hour experimental period was considered to be an extinction period where the unconditioned stimuli and reinforcement were absent which resulted in extinction of conditioned response. According to this theory decrement occurs due to the development of an inhibitory state. Inhibition is a fatigue like construct which develops in absence of reinforcement. According to Mackworth knowledge of result and rest pauses can counter effectively with this inhibitory phenomenon. The theory is criticized by Deese (1955), who argued that vigilance performance not necessarily decrease with time, it may go up and down. Another problem with this theory was that with increase in frequency of signal the inhibition should built up very early but it does not happen. In 1958, Holland proposed the theory of observing responses. According to him, vigilance performance is an operantly controlled observing response, consisting of eye and head movement. Further, eye movements and head movements continue to occur, they are reinforced by the occurrence of detectable signals, and they are extinguished in the absence of such signals. In a

number of experiments eye movements were recorded as indicator of the observing response. Studies (Mackworth, Kaplan, & Metlay, 1964) have reported that signals at a display are often missed when observers look at wrong display; signals are also often missed when observer eyes were correctly positioned toward the display. Furthermore, Coates, Loeb and Alluisi, (1972) found that it was not critical for observer to have their eyes centered for detection instead they can apply better observing strategy.

The second, neurological models include arousal theory and habituation theory. Frankmann and Adams (1962) regard arousal level responsible for vigilance decrement. Arousal theory hypothesized that an optimal arousal level is essential for performing a task and either a decrease or increase from optimum level of arousal impairs performance. They suggested that the target stimulates the observer but with repeated presentation of the same stimulus or very similar ones (target and non-target) the arousal level either decreased or gets habituated. This theory talks about two closely related hypotheses of vigilance decrement i.e. decrease in arousal level and habituation of arousal response. This theory assumes a link between physiological arousal and vigilance performance (Davies & Parasuraman, 1982). Sharpless and Jasper (1956) were among the first to report the phenomenon of habituation of arousal, and they also suggested that the performance decrement found in vigilance and other monotonous task may be due to this process. Later on, Mackworth (1968) proposed habituation theory which was a variant of arousal theory. This theory suggested that neural or behavioural response may be habituate if it is reduced in amplitude or eliminated as a result of repeated stimulation resulting in impaired vigilance performance.

Information processing models include filter theory, expectancy theory and signal detection theory. Filter theory (Broadbent, 1958) assumes that the monitor's information-handling capacity is limited and that information is selected by a filter biased to receive information from some sources and reject it from others. Due to continuous filtering of non targets subject sometimes could not differentiate between target and non target therefore missing the target. Expectancy theory (Baker, 1959; Deese, 1955) states that the observer forms the expectancies about the probable occurrence of signal (target) on the basis of his prior experience in the task. The observer develops a self estimated average of signal presentation and is charged up to attend the same. However, if temporal gap between occurrences of two target signal is fixed then due to expectancy performance improved. The theory is criticized as the estimation of short interval of time comes under suspicion (McGrath & O'Hanlon, 1967) and the role of temporal expectancy is doubtful (Davies & Tune, 1970). Green and Swets (1966) proposed signal detection theory which assumes that observers' performance during vigilance task may be explained on the basis of observers' sensitivity and response criterion. Decline in performance is either consequences of decrease in the sensitivity or due to development of more rigid response criterion across time period. The studies suggested (Parasuraman, 1979) that the decrement in sensitivity occurs only if the detection system has to utilize information from short-term stores that are subject to interfere at high stimulation rates (in successive-discrimination task). This mechanism may be conceived to be operative at an early stage in the flow of information through nervous system and probably involves the efficiency of neural units concerned with the detection of critical signals in the environment. If the vigilance task does not load short term memory or if the event rate is low, the decrement results from changes in decision criteria. This mechanism associated with the decision process leading to the selection of a response, and may therefore operate at later stage (Parasuraman, 1984).

In light of the reviewed theories, a number of commonalities exist in their predictions. The physiological theories such as arousal, inhibition, and habituation, along with Broadbent's filter theory, maintain that higher signal and event rates should result in a greater decrement in detection performance due to habituation or the reduction in stimulus novelty and biological importance. Expectancy and reinforcement theories all predict

improved performance with knowledge of results and prior knowledge of signal probabilities. Although numerous theories have been proposed to explain vigilance performance, no one theory can make specific performance predictions for different experimental paradigms and real-world contexts. In fact, correlations between vigilance performance on different visual and auditory tasks are extremely low (Parasuraman & Davies, 1977). With poor correlations, many authors have proposed that vigilance performance is difficult to predict from task to task due to different task dimensions and complexity. Parasuraman and Davies (1977), in a review of the literature, cited such divergent task dimensions as: source complexity, sense modality, response type, sensory coupling, signal duration, time course of events, attentional requirements, stimulation values, and task abilities. With so many factors affecting performance, it is no wonder that no one theory of vigilance has been successful in predicting performance and hence, suggesting to adopt taxonomic approach to study the underlying factors of vigilance performance.

Mindlessness vs mindfulness controversy

Even though vigilance has been investigated for over 60 years by researchers, there remains significant debate regarding the underlying cause of the vigilance decrement. In previous section of present paper numerous theories have been discussed but none of them could reach to a specific conclusion to explain the causative factors related to vigilance decrement. Recently, there are two broad families of theories of failures of sustained attention widely debated among researchers. The first family of theories posits the decrement in vigilance performance to be due to mindlessness, boredom, or cognitive under-load during vigilance tasks (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). The second family of theories posits the vigilance decrement to be due to resource demand, mental fatigue, or cognitive over-load of vigilance tasks (Helton & Warm, 2008; Warm, Parasuraman, & Matthews, 2008).

Robertson and his colleagues (Manly et al., 1999; Robertson et al., 1997) proposed the mindlessness view of vigilance decrement by adopting the view of Shallice and his associates (Shallice, 1988; Stuss, Shallice, Alexander, & Picton, 1995) which contend that in a typical repetitive vigilance task where signals are separated by long intervals, supervisory attentional system loses its strength and observers cease to focus their awareness on the task at hand. According to this view, mindlessness is defined as a thoughtless, routinized approach characterized by withdrawal of effortful attention away from the task at hand. During vigilance task, critical signals for detection occur rarely, the relative inactivity between critical signals makes observers increasingly disengaged or mindless. The lack of exogenous support for alertness during the gaps between critical stimuli fails to keep observers attentive to the task and this eventually leads to their lack of awareness to the critical stimuli.

Robertson and his associates (Manly et al., 1999; Robertson et al., 1997) have introduced a modification of the standard vigilance paradigm designed to increase the degree of mindlessness in which monitors are required to respond overtly to nonsignals and to withhold responding to signals. They assumed that repetitive responding to considerably more numerous nonsignal events in modified vigil task will generate the routinization, automaticity, and attentional lapses in observers which may lead to detection failure. The Robertson group found support for the general role of mindlessness in vigilance and for its specific role in their modified task in their observation that absent-minded individuals, defined by high scores on the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper, Fitzgerald, & Parkes, 1982), do more poorly on the modified task than do those who have low scores on the CFQ.

In the mindlessness theory of vigilance, primary interventions were made to reduce task monotony and to perk up the attentional capacity by including content-free cues. Manly et al. (2004) found a benefit of additional irrelevant stimuli. Though, the subsequent studies have failed to see benefits from content-free cueing (O'Connell, Bellgrove, Dockree & Robertson, 2006). From the

description of the characteristics of the above notion one could gain the impression that vigilance tasks are tedious and understimulating assignments that impose little workload upon observers. An impression of that sort has formed the basis of the long-standing arousal theory that accounts for the vigilance decrement in terms of a lack of stimulation necessary to maintain alertness. Similar to mindlessness theory, Ariga & Lleras (2011) proposed a new theory of vigilance decrement: goal habituation. This theory is more cognitive in scope, using sensory habituation only as an analogy. They propose that the cognitive control system is unable to maintain the goal of the vigilance task over time and the goal itself habituates with time on task. They, therefore, suggest that by temporarily deactivating the vigilance task goal, goal habituation and the vigilance decrement can be eliminated. The goal-habituation theory while unique does seem to fit within the broader under-load family of theories of vigilance.

The validity of mindlessness model has been contested by the Grubb et al., (1994) who found that absent-minded monitors perform as well on a traditional vigilance task as non-absentminded monitors but rate that task as more mentally demanding on the NASA-TLX than do non-absent minded individuals. In a recent study, Seli, Cheyne and Smilek, (2012) found that the content unrelated cues actually impaired performance and in similar context, the inclusion of highly arousing task-unrelated stimuli during vigil task has significantly detrimental impact on vigilance performance. This later findings are actually more in line with the resource theory perspective of vigilance, in which the content-free cues may consume resource necessary for task performance (e.g. resource competition).

Resource theory is a constituent of mindfulness view of vigilance decrement. Advocates of resource theory argue that the information processing resource required for vigilance are limited (Davies & Parasuraman, 1982; Grier et al., 2003; Helton & Warm, 2008; Warm et al. 2008). Vigilance tasks require observers to make continuous signal/noise discriminations under conditions of uncertainty without rest. The continuous information processing demands of vigilance task deplete the necessary cognitive resources resulting in decline in performance efficiency over the watch-keeping session (Helton & Warm, 2008; Hitchcock, Dember, Warm, Moroney& See, 1999; Hitchcock et al. 2003).

The mindfullness perspective is supported by behavioural studies, brain imaging studies, and mental workload studies. Generally, manipulations that objectively increase task difficulty (for example increasing memory requirements, decreasing signal salience, or adding spatial/temporal uncertainty) result in more lapses of sustained attention (See, Howe, Warm, & Dember, 1995). This would be consistent with the perspective that increasing task demands result in more resources consumption and this depletion of resources results in lapses. Recent brain imaging studies indicate several regions associated with vigilance, including the anterior cingulated cortex (ACC), right prefrontal cortex, right inferior and parietal regions, and the thalamus (Lim et al., 2010). The ACC and prefrontal cortex contribute to the top-down control necessary for the maintenance of vigilance (Lim et al. 2010). The vigilance decrement is matched by declines in cerebral blood flow (CBF) with time on task (Hitchcock et al. 2003). In addition, vigilance task impose a substantial mental burden upon monitors, as reflected in high scores on measures of perceived mental workload and stress (Warm et al. 2008). Indeed, the vigilance decrement most strongly correlated with observer's feeling of mental fatigue or exhaustion, thus providing a phenomenological account for resource depletion (Helton & Warm, 2008). Finding of Grier et al. (2003) support the prior studies (Hitchcock et al., 1999; Temple et al., 2000) that vigilance task induced a high level of workload, and that workload was similar in the standard and modified conditions. In addition, monitors in this experiment, as in others using the DSSQ reported the vigilance task to be stressful. Studies employing self-report indices have demonstrated task-induced negative mood shifts and increases in restlessness, subjective fatigue, sleepiness, and headaches across the vigilance task

(Hancock & Warm, 1989; Warm, 1993). Similar to transactional models of stress, in which stress is viewed as arising from individuals' appraisal of their environment as taxing or exceeding their coping resources (Matthews, 2001), these results are also consistent with the idea that detection failures in vigilance stem from capacity drain brought about by prolonged effortful attention.

CONCLUSION

The classical problem of vigilance i.e. vigilance decrement has been described as increase in reaction times or decrease in accuracy as an effect of time-on-task during tedious monitoring tasks. Different theories like learning theories, neurological theories and information processing theories failed to predict the underlying cause of vigilance decrement. Though, in literature controversy remained whether the decrement during vigilance occur due to withdrawal of the supervisory attentional system, due to underarousal caused by the insufficient workload, or to a decreased attentional capacity and thus the impossibility to sustain mental effort caused by higher workload. The first view is called as mindlessness view and the later as mindfulness. In the view of available studies it seems that vigilance decrement is better characterized by effortful attention i.e. mindfulness than by mindlessness view.

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