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Individual Differences in Vigilance Tasks

Project Leads

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Statement of Problem

Within the U.S. Department of Homeland Security (DHS), a number of occupations (e.g., baggage screening, passenger screening, dispatch, incident command) require sustained levels of attention by an individual—what is termed “vigilance” in this paper—and share four main characteristics:

- The individual must be vigilant to potentially subtle or rare occurrences.
- The individual's responses do not influence subsequent occurrences.
- There may be high stakes for missing subtle or rare but relevant items.
- The individual might be required to stay “on task” for extended periods of time.

Much research relating to vigilance has focused on occupations somewhat outside the scope of DHS (driving, piloting, air traffic control, and military specialties); however, findings from these areas can be carried over into DHS-related tasks.

In addition, relatively little research has focused on individual differences in vigilance. Some literature suggests individual differences may exist in the ability to maintain vigilance for a rare target over long time periods. However, it is an open question whether some individuals can maintain vigilance fairly easily while others cannot.

Finally, some research has considered if and how vigilance can be trained or improved. If an individual is assigned a duty that requires sustained vigilance, then it would benefit the individual's agency to be assured of his or her competency.

Thus, the research questions are as follows: *Are there individual differences in the inherent ability to sustain vigilance, and what are the most effective approaches for training and improving sustained vigilance for rare items or events?*

Background

Vigilance is sustained attention as it is influenced by the nature of a given task, that is, the performance required of the individual. The term "attention" describes (1) the cognitive processing involved in orienting to and selecting among specific items or responding to possibly infrequent changes in what is presented, (2) the mental effort dedicated to this processing, and (3) the state of alertness or readiness to process additional items (Matthews Davies, Westerman, & Stammers 2000; Washburn, Tagliatela, Rice, & Smith 2004). The task may involve items with high or low salience, complexity, or uncertainty in presentation and may also involve the presence or absence of background signals. Attention can be auditory and/or visual, may involve one or more items to identify that must be maintained in working memory, may involve frequent or rare items, and may demand a higher-level situation awareness. All of these task demands, then, can influence an individual's vigilance.

Studies have considered a number of approaches to overcoming deficits in the performance of vigilance tasks, including automated aids (Warm, Dember, & Hancock, 1996; Wiegmann et al., 2006); manipulating predictor information or target expectancy (Singh, Tiwari, & Singh, 2007; Szalma et al., 2006; Wickens, Gempler, & Morphew, 2000); improving posture (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen 2002; Drury et al., 2008; Ehrenfried, Guerraz, Thilo, Yardley, & Gresty, 2003; Liao & Drury, 2000); administering caffeine (Tharion et al., 1997); and even managing ragweed-induced allergic rhinitis (Wilken, Berkowitz, & Kane, 2002). However, not all of these approaches are relevant to DHS vigilance tasks. Specific to DHS-relevant training, Uenking (2000) used a cognitive training exercise to sharpen pilots' awareness during simulated flight, thereby providing them with a means to overcome boredom, sleepiness, and fatigue. Meanwhile, McCarley, Kramer, Wickens, Vidoni, and Boot (2004) showed that practice can improve sensitivity and response times within a simulated luggage-screening task, though these improvements diminished with non-familiar targets (see also Smith, Redford, Washburn, & Tagliatela, 2005). Practice, then, at least within certain bounds, can improve individuals' performance on vigilance tasks.

Some research suggests that most individuals, when they are motivated (e.g., through instructions or incentives), are good at resisting distraction and staying on task, that is, attentive (Smith et al., 2005). But individuals must know to maintain attention; some evidence indicates that individuals tend to miss items when multiple items are present (e.g., in a

radiologic exam or in a baggage screening). Most of this capability lies in our “executive control”—our ability to impose our will over environmental or experiential urges. However, there are individual differences in executive cognitive functioning (Fishbein et al., 2006), suggesting that individuals might vary in how well or how long they can maintain control given the initial motivation. Motivating individuals, then, can (within certain bounds) improve their vigilance.

There are other individual differences—particularly personality and age—that are known to influence performance on vigilance tasks. Many such variables have been considered in previous research, both temporary individual differences, such as learned coping strategies and level of fatigue, and stable individual differences, such as introversion/extroversion, sleep behavior, age, and gender (e.g., Basner et al., 2008; Eysenck, 1989). Further, it is known that “bottom-up” processing (as opposed to “top-down” processing that is characteristic of executive control) of aspects of the task, such as salience of items and similarity or difference between targets and distracters, greatly influences task performance, but this influence can depend on an individual’s prior experience. Overall the research has yielded reasonably consistent results but points to a need for further understanding of the mechanisms involved that cause individual differences in performance (Casagrande, 2002).

Moreover, certain aspects related to the individual’s environment can be modified to improve or maintain vigilance. For instance, Humphreys and Revelle (1984; see also Davies & Hockey, 1966; Derryberry & Reed, 2001) modeled an individual’s arousal and effort as a function of the task demands as well as personality dimensions. Similarly, Thiffault and Bergeron (2002) found personality predictors of fatigue during a driving task. Also, Ishizaka, Marshall, and Conte (2001) considered a specific personality trait (Type A behavior pattern) and its influence on simultaneous tasks. All of these studies found that different types of individuals (using different personality measures) are more or less vigilant on the various tasks presented. Meanwhile, Madden, Gottlob, and Allen (1999) found age differences in visual search accuracy, and Endsley and Bolstad (1994; also Engle, Kane, & Tuholski, 1999) measured individual variation in a number of cognitive capabilities (e.g., working memory capacity, perceptual speed, pattern-matching ability) and found consistent individual differences in performance on situation awareness tasks. It is not obvious how performance differences reflected by personality or age or relatively static cognitive capabilities can be overcome by training. Instead, these may be factors that influence the type of vigilance task assigned to the individual or the time period over which the sustained attention must be maintained.

A number of studies have considered neurophysiological and biological implications of vigilance tasks, considering measures such as neural electrical activity, nocturnal salivary melatonin concentration, circadian phases, heart rate, and cerebral blood flow (Higuchi, Motohashi, Liu, Ahara, & Kaneko, 2003; Hitchcock et al., 2003; Horowitz, Cade, & Wolfe, 2003; Paus et al., 1997; Sarter, Givens, & Bruno, 2001; Seidman et al., 1998). Some of these

neurobiological implications can be influenced by training (Lutzenberger Elbert, Rockstroh, & Birbaumer, 1979; Prinzel, Freeman, Scerbo, Mikulka, & Pope, 2003; as well as Army and Marine Corps Combat Operational Stress Control programs), such as deep breathing and biofeedback exercises. Hence, it is possible that given such training, individuals may be able to handle longer or more complex vigilance tasks, but few such studies have been performed.

Biologically based approaches to modifying vigilance performance consist primarily of pharmacological agents (i.e., drugs or medications) and recent noninvasive neurotechnologies such as repetitive transcranial magnetic stimulation (rTMS) or weak transcranial direct current stimulation (tDCS) that target specific regions of the brain. Sample pharmacological agents are caffeine and modafinil; the latter is a particularly interesting drug that has potential for remediation of cognitive dysfunction (Minzenberg & Carter, 2008) and for applications in which sustained vigilance is essential, despite fatigue or sleep deprivation. However, many psychostimulant drugs exhibit a biphasic dose-response curve in which low doses of the drug are generally beneficial to cognitive processing, while high doses cause side effects (jitteriness, anxiety) that interfere with performance (Calabrese, 2008). This biphasic characteristic, as well as the potential for habit-formation, limit such agents' utility for vigilance enhancement (but see Tharion et al., 1997).

Also of interest, noninvasive technologies to influence neural functioning in targeted brain regions hold promise. For instance, there is initial evidence that these technologies may facilitate neural plasticity, a characteristic that could potentially make short-term use in conjunction with cognitive training programs lead to long-term gains. That is, localized brain stimulation may facilitate retraining for improved vigilance performance. Long-term effects of continued neural stimulation, though, are not completely understood.

Synthesis

These research results suggest, overall, that individual differences do exist regarding vigilance task performance and that some forms of training or intervention can apply, given specific tasks, conditions, and standards of performance. Koelega, Brinkman, Hendriks, and Verbaten (1989) were able to dissociate vigilance level from vigilance decrement, showing that the level relates to effort expended while decrement relates to the task demands. This finding implies two different approaches to improving sustained vigilance.

First, it is important to consider how a given task affects different components of working memory and, accordingly, to design vigilance tasks so that individuals can tap into concurrent capabilities (e.g., the ability to process visual cues separately from processing textual content) and not overtax one working memory component. Caggiano and Parasuraman (2004) found that sensitivity in a vigilance task declined over time when the concurrent task involved spatial working memory, but not when it involved a non-spatial working memory task. In similar work, St. John and Riser (2007) found that individuals who demonstrated greater vigilance

decrements at an earlier time showed more improvement when secondary tasks drew upon resources separate from the primary visual vigilance task. Also, Martens, Johnson, Bolle, and Borst (2009) showed that individuals differ in their visual versus auditory attentional capabilities. Thus, one approach to overcoming vigilance decrement might be to employ different modalities; this applies more so for individuals who prefer one modality (e.g., visual detection) over another (e.g., auditory detection). As one practical example, baggage screening might mainly employ visual input (such as imaged content of luggage), but also use auditory input (such as specific sound alerting) to draw the screener's attention towards suspicious items or materials or even suspicious passenger behavior.

Second, in relation to vigilance level and effort, an approach to improving sustained vigilance might be to motivate individuals and allow them to practice on relevant materials. A study of rare items found that these items were often missed in visual searches and that errors in spotting key targets increased substantially if they appeared only infrequently during screening (Wolfe, Horowitz, & Kenner, 2005). Individuals, it appears, require a threshold for quitting their search when no target has been found, and this threshold is constantly adjusted, so that they slow down after making mistakes and speed up after successes. Similarly, Rich and colleagues (2008) studied the “prevalence effect,” described as missing a disproportionate number of targets in visual search tasks with rare targets. Low target prevalence places individuals under pressure that tends to increase miss errors, with the specific source of those errors depending on the nature of the search.

Finally, Fleck and Mitroff (2007) showed that misses on rare events result from the way individuals respond (not from their perception or misperception of events), so enabling individuals to correct their initial responses can dramatically improve performance. The implication of these findings is to address not only the working memory demands of the task, but also the expectations set up by the task. One training approach—or even a practical on-the-job approach—could be to purposefully (and artificially) introduce otherwise rare items into a training/work environment to boost confidence and the individuals' ability to distinguish those rare items from more common ones. A parallel approach could be to introduce an automated spatial cuing aid, such as a highlight on the screen to draw attention to suspicious items, particularly for older individuals for whom spatial cuing helps more than text or verbal alerts (Wiegmann et al., 2006).

Future Directions

The above are somewhat general observations for how to improve vigilance performance. They are not specific recommendations to implement the training or alteration of task demands to meet individual needs. More research is needed to advance the understanding of individual differences in vigilance tasks, including assessment of the impact of training and neural

stimulation. Two specific example areas to operationalize future work are given (building upon established work) that could immediately address the general observations presented above.

The first example area is to implement simulation training to motivate individuals and allow them to practice on vigilance skills. Past research established broadly accepted modes of learning within simulations that have been shown to yield procedural (e.g., Frank, Helms, & Voor, 2000) and interaction (e.g., Hubal, Kizakevich, & Furberg, 2007) skills competencies. The simulation enables acquisition, practice, and validation of skills, but also manipulation of demands imposed by the task (e.g., by changing the environment or response characteristics) to tailor each task to individual and performance requirements. Using game-like environments for implementing the simulations is currently a very popular approach in research labs; games are seen as engaging and motivating and therefore are a key component to the serious simulations needed for training.

The second example area to improve sustained vigilance is quite novel, centering on potential applications of neural stimulation (e.g., tDCS), or new pharmacologic agents (such as modafinil, which, in the current context, may provide a benchmark against which to compare cognitive-behavioral training, other pharmacological, or innovative neural stimulation techniques). Different experimental paradigms, such as attentional blink (the phenomenon of a deficit occurring when the second of two targets follows the first too closely) and situated assessment (representing yet another usage of simulations), would be used to assess the effects of these stimulants on performance.

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