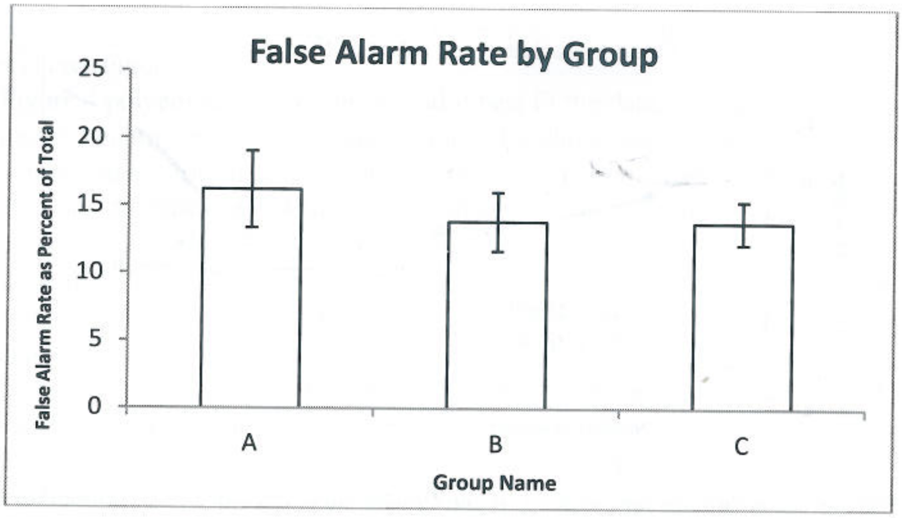

Figure 6. Our data show no significant increase in the number of false positives as the number of threats increases (Kruskal-Wallis rank sum test, p=0.160). Average false alarms with whiskers indicate standard errors of the mean for each of group.

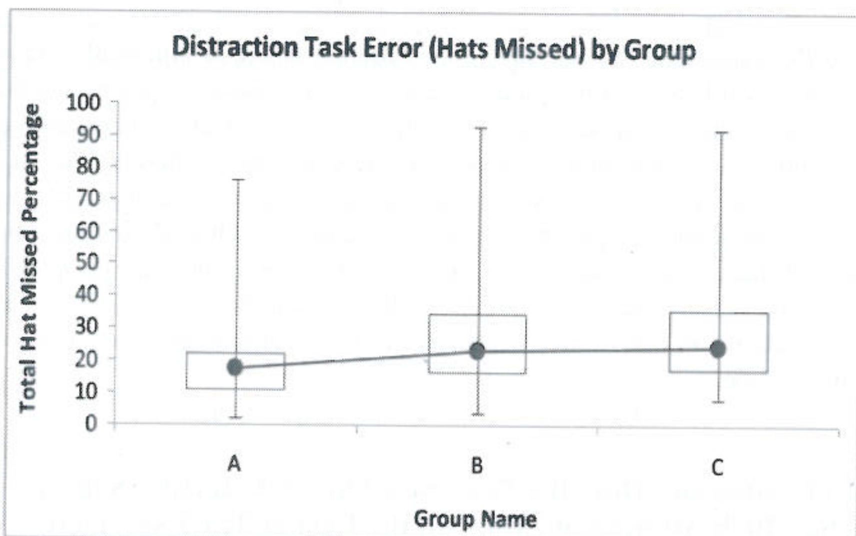

Figure 7. The chart shows the distraction task errors per group, with points at the median, boxes around the inter-quartile range, and whiskers showing the minimum and maximum values.

The number of false positives was about 8 per group, or an average of about 1 error per 15-minute period. Our results are not consistent with those of Richards et al. (2012), who found that the accuracy of the distraction task remains unchanged whether or not participants are proficient at noticing the inattentional blindness target.

The purpose of the distraction task was to simulate real-world noise. The generally low error scores for the distraction task suggest that this task was not difficult. Other prevalence effect experiments did not include a distraction task at all (Wolfe et al., 2007; Wolfe and van Wert, 2010), and (Evans et al., 2011b), so we do not need to be concerned that the relative ease of the distraction task changes our understanding of the prevalence effect.

3.5. Research Question: How Is the Proposed Threat-Detection Solution Influenced by User Gender, Age, and Amount of Sleep?

Effect of sleep. We wanted to measure whether participants' amount of sleep the night before the study influenced alertness to the extent that it influenced threat detection accuracy.

Our study accepted participants' self-report of their number of hours of sleep the night before the experiment. Because we gave participants no reason to bias their response, we trust that their answers are reliable.

The data show no correlation between the amount of sleep the night before the experiment and the error rate in the threat detection task, (Spearman's rank correlation ρ=-0.076, p=0.43) (Figure 8). That implies that the attention level for target detection is not greatly affected by the previous night's sleep. Decision-making judgment in another experiment had been shown to be impaired by lack of sleep (Fraser et al. 2013), but participants in the Fraser study were forced to be awake unnaturally for the entire night, so the effects of lack of sleep might have produced more fatigue than a natural sleep cycle as perhaps in our experiment, which often includes some wakefulness. Even so, in our study, we do not know whether participants' relative lack of sleep the night before the study was a single occurrence, or whether they had experienced several nights of inadequate sleep in succession. Sleep deprivation would produce more cognitive effects that a single night of little sleep.

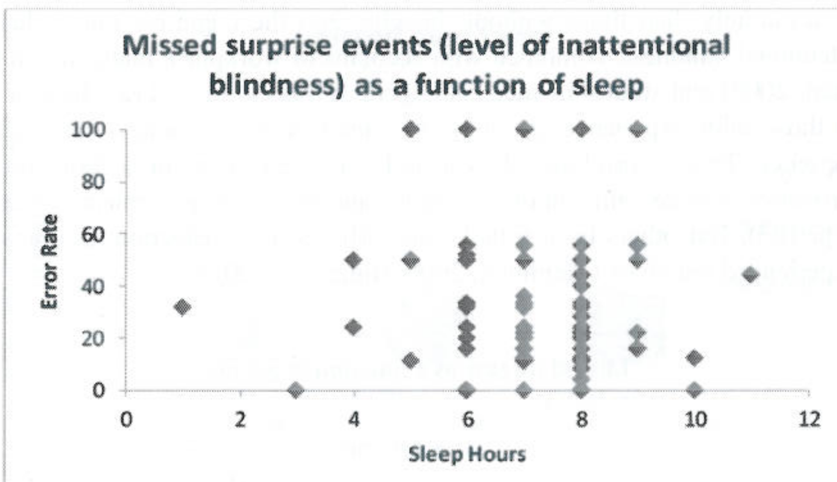

Figure 8. The chart shows no relationship between the number of hours of sleep and participant performance (Spearman's rank correlation ρ=-0.076, p=0.43).[11]

Effect of age and gender. We tested whether the parameters of age (Figure 9) and gender (Figure 10) correlate with threat detection accuracy.

[11] Rho ranges from -1 (perfectly negatively correlated) to 0 (uncorrelated) to 1 (perfectly positively correlated). The p-value ranges from 1 (highly probable by chance) to 0 (unlikely by chance). Uncorrelated variables will give rho near 0 and large p-values. Correlated variables will give rho near +/- 1 and small p-values. Spearman's rank correlation measures the correlation between two variables. There is one measure of the strength and direction of the correlation (rho) and one measure of the significance of the correlation (p).

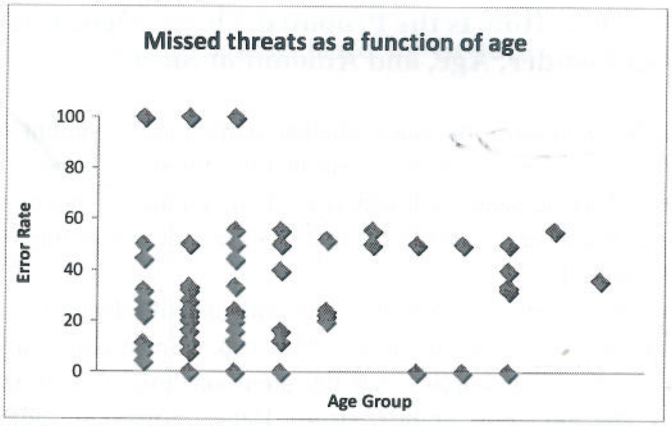

Figure 9. The chart shows no relationship between age and error rate (Spearman's rank correlation ρ=-0.015, *p*=0.88).

We found no correlation with age (Spearman's rank correlation ρ=-0.015, *p*=0.88), and no correlation with gender (Wilcoxon rank sum test, *p*=0.53). Schwaniger et al. (2007) and Richards et al. (2012) also found no effect of age on performance, although neither study team considered gender.

Effect of experience. Only five of our participants had had security experience, so we were unable to do any statistical inference to determine whether those with experience spotted threats more accurately than those without. Insights into the cognitive rather than learned basis of inattentional blindness, combined with accounts of workplace inattentional blindness error (Hallinan, 2009) and studies of medical experts (Evans et al. 2011a; Drew et al. 2013) suggest that those with experience are subject to inattentional blindness just as are those without experience. This is corroborated by a study of threat image projection software that found no correlation between amount of experience and detection performance (Schwaninger et al. 2007, p. 123). But others have found some difference in detection accuracy between naïve and experienced searchers (Memmert, 2006; Biggs et al. 2013).

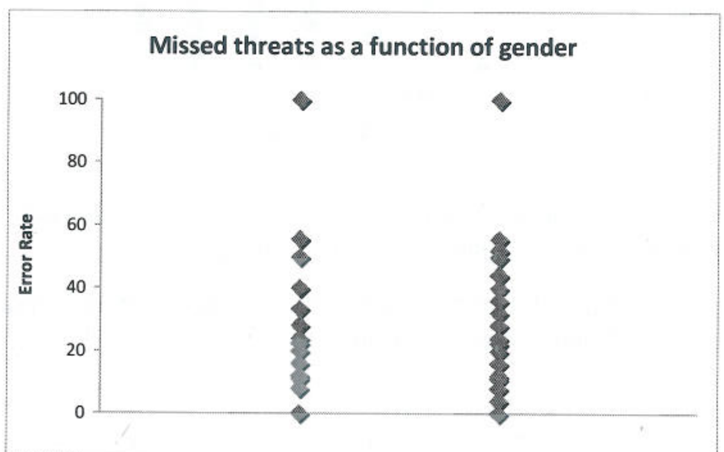

Figure 10. The data show that the error rate does not vary significantly by gender (Wilcoxon rank sum test, *p*=0.53).

3.6. How Is the Proposed Threat-Detection Approach to Heighten Attention via Increased Artificial Event Frequency Influenced by the Amount of Time the Person Has Been Working?

We would like to know whether the proposed solution is temporary or robust to long working hours, and whether heightened attention to some target can be maintained over time. So we compared the self-assessment data from the post-task questionnaire to performance results. This allowed us to judge whether the length of the study affected response accuracy such that there were maturation effects (did the person learn and so perform better over time?) or fatigue (did the person get tired and so perform worse over time?).

We checked for the influence of study duration by comparing threat detection results among time frames of the first, second, and final third of the experiment (Figure 11). We did not include Group A in this analysis because there were no threats in the middle third of video A. The data for Groups B and C show that the error rate did not increase from the beginning of the study to the end for either Group B (Kruskal-Wallis rank sum test, $p=0.15$) or Group C (Kruskal-Wallis rank sum test, $p=0.13$). Thus, the level of inattentional blindness did not drop significantly over time. The conclusion is that the prevalence method would continue to heighten attention and improve target detection over multi-hour working shifts.

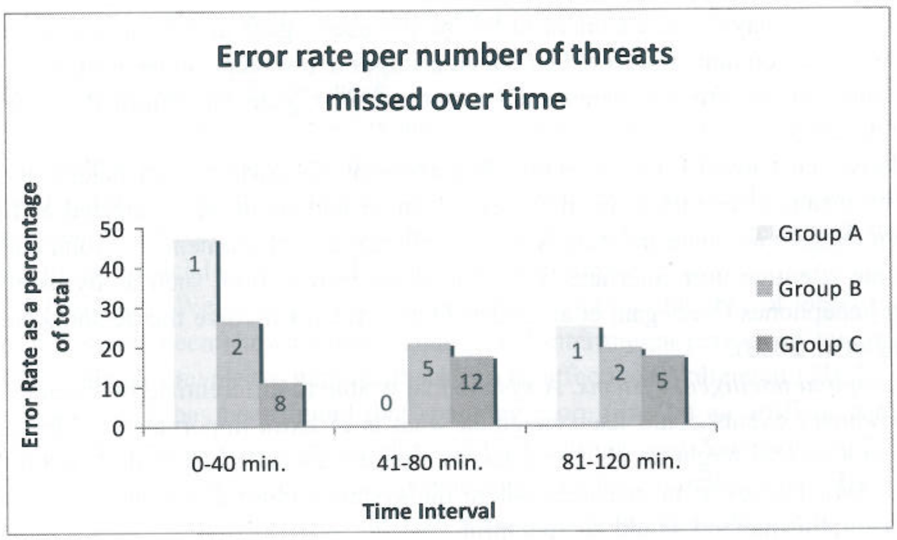

Figure 11. The chart shows the error for each group divided into three time intervals. The number labels within the data bars indicate the actual number of threats in each time segment of the video.

3.7. Experiment Result Limitations

The time commitment required from participants and the relatively high compensation required to pay them served to limit the number of participants we were able to test. The outcome is that the generalizability of our findings is limited by the size of the groups.

Some unreliability remains in the data we collected, as revealed by the exit survey. In the survey, some participants commented that they did not use the "Remove" bar in time, and left error in their scores knowingly.[12] This happened despite the fact that we had included preliminary drills on threat identification during the instructions session that preceded the experiment, and we had encouraged the participants to refer to the description of threats on the instructions sheet while they took the experiment, and to use the "Remove" bar during the demo session just for practice. Specifically, some participants admitted in the exit survey that there were instances in which they were unsure whether they were responding to a threat or ordinary activity. Characteristics of the experiment that made threat identification unreliable should be explored further, especially for those who plan to use our videos for continued experimentation.

IV. Insights toward Building a System That Heightens Attention

4.1. Related Work

Attention and vision. Attention Aware Systems present the user with newly-available data that minimizes disruption to on-going tasks. Users may choose not to examine that data or may shift their attention without prompting by the system (Roda and Thomas 2006). Displays known as "diff displays" use a camera to follow the user's gaze and determine whether the focus is toward the computer screen. Unnoticed changes to a screen can be brought to a user's attention once the system has determined that the user's gaze has returned to the screen (Dostal et al. 2013).

Similarly, the Closed-Loop Attention Management (CLAM) system detects the user's attention by means of eye tracking. If the eyes wander and attention is detected as flagging, this system triggers a countermeasure to raise vigilance at that moment (St. John and Risser 2008). Some attentive user interfaces filter irrelevant information, such as by using noise-cancelling headphones (Vertegaal et al. 2006). Other systems involve the person's emotional state (Jiang et al. 2006).

Attention and intelligent systems. A system that is able to differentiate between every day and extraordinary events could itself heighten what is of extra-importance (Aldridge et al., 2003). Such a system might be able to detect certain events and deliver alerts automatically (Durlach 2004). However, in instances where the system cannot discriminate which events are significant, this method would be unhelpful.

Attention and the prevalence effect. The prevalence effect is the scientific basis of Threat Image Projection software, in current use by some airport screeners in the United States and Europe. The way the software works is that threat images are projected onto travelers' bags, and screeners respond to those images, for the purpose of enhancing their awareness to potential threats that are real. But the effectiveness of this Threat Image Projection software remains disputed. It has been conjectured that the software becomes ineffective because the threat image library is too limited, so the proposed fix was to use a wider threat image library

[12] The "Remove" bar only was effective within about a minute of the initial participant response. We could not increase the window of time "Remove" would be effective because sometimes events or hats follow each other in quick succession, and sometimes in the same quadrant. Widening the time window thus would have introduced error by potentially removing the wrong action.

(Schwaninger et al. 2007). It may alternatively be conjectured that the threatening objects projected by the software are unrealistic and so awareness is not heightened to threatening objects that are real. If this were the case, a fix would be to encourage more attention to the type of image object rather than to the image itself by interspersing threatening and non-threatening objects as foils.

It has been proposed that initial training with the software should include understanding of the purpose of the artificial images (Cutler and Paddock 2009). Our experiment shows, however, that participants do not need to understand the science in order to reap cognitive benefits in terms of heightened awareness.

4.2. Our Approach to Heighten Attention: Design of an Automated System

We recommend the use of an artificial event response system based on the prevalence effect, with user responses and intelligent system feedback that will heighten awareness and reduce the number of misses. Differences with the Threat Image Projection software include that our framework is modeled in another domain, and our system would respond to user misses by feedback text cues, and also by image placement, etc. Aspects of the proposed framework appear below to answer the final research question: How would a threat-detection computer system or protocol look that implemented this solution?

Elements of Our Proposed Framework

This framework includes aspects beyond what was modeled in our experimental setting, in order to heighten attention even more effectively.

Artificial targets. Real-time footage would be overlaid with artificial images of the same nature as real-life targets. Users would respond to the artificial targets, and the act of responding to the artificial should heighten awareness of the actual.

Target frequency. We have preliminary data on an optimal number of target events per unit time. It has also been shown experimentally that intermittent periods of low prevalence and periods of higher prevalence with feedback can be effective (Wolfe et al., 2007).

User response. It has been found that spending more time on an artificial target event helps reinforce the memory of it (Most el al. 2005; Bradshaw and Anderson 1982). For this reason, the user response required by the system might be for example a short description of the threat object, in order to encourage the user's thoughts to linger on the episode.

System feedback based on user response. After the user inputs a response, the system would show the user which responses were hits and which misses. Such feedback in addition to the repetition of targets can aid learning, and so would likely increase attention further. Sample feedback might be "Good, you found the target." Or "Look again—no target is present," with an option to go back and allow the user to find his mistake. Note that our test system did not provide on-going feedback in this manner because our goal was to measure inattentional blindness rather than to correct it.

System intelligence. The artificial targets would be displayed in random order and at random locations on the computer monitor. But after some time, the system would draw on stored user responses to intelligently display targets in type and in screen location to emphasize target types and screen locations that had been missed. User misses might change over the long term, so that system memory of user responses and intelligent target placement should be continuous.

Comments on Our Proposed Framework

Does our approach increase time and workload? We found that participants took slightly more time to respond in the high prevalence condition. Cain et al. (2012) found also that participants searched for a longer time in the higher prevalence condition. But with the drawback of a slightly longer search time would come the advantage that potentially more threatening activities or objects would be spotted. So the advantages of the method outweigh the disadvantages of slightly longer decision time and increased decision-making.

Does our approach decrease effectiveness at simultaneous tasks? We found that out approach did decrease effectiveness at the simultaneous task of hat counting somewhat (Figure 7). More importantly, our approach raised effectiveness of the core task of threat detection (Figure 3), and our approach did not raise the number of false alarms, that are innocent events called threats incorrectly (Figure 6).

Additional expense incurred by our approach. Consider these artificial targets and the time spent viewing and responding as an additional safety precaution. The point of surveillance in the first place is to find anomalies. Therefore, finding more anomalies will improve effectiveness. Those who sponsor monitoring and are responsible for consequences, such as airport security or hospital management, should be prepared to subsidize additional measures whose potential benefits are life-saving.

Is our approach generalizable? The efficacy of prevalence to improve target detection has been proven in the medical domain (Evans et al. 2011b), as well as in this study in the domain of security. Hence, our approach, resting upon principles of cognition, should be applicable beyond building security. Other situations where this approach might be relevant include underwater monitoring, wider city security or other medical slide or scan screening.

4.3. Hybrid Approach to Heighten Attention: Computer + Non-Automated Means

The intelligent, automated artificial event feedback system can be combined with non-automated approaches, such as are described below.

Covert testing. It has been recommended for airport security that artificial image systems be reinforced by acted-out procedures, in what is called covert testing (Schwaninger 2009). A covert test in airport security might consist of an unidentified person walking through a checkpoint carrying a weapon on his person or in luggage. This is covert because the guard being tested would not know about the test beforehand. It has been found that security officers' alertness improved after on-going covert testing (Wetter et al. 2008). If staff is limited, covert testing could be carried out by familiar people who will carry nothing out of the ordinary in some trials, but will conceal weapons in other trials. The covert, unknown aspect would then come with the individual trial rather than with the individual person.

Viewing redundancy. Fewer mistakes would be made if we were to arrange for more than one person to do the viewing task simultaneously. A second screener could examine the same monitor display off site, for example. Two screeners' independent responses to the same monitor images would serve to verify one another. That is, their individual judgments would be correct with higher confidence if both screeners delivered the same response. But if their responses disagreed, an immediate warning could be sent to both to look again, or to the on-site screener to examine the actual situation more carefully. The disadvantages are that each person independently is subject to attention lapses – so mistakes will still be made – and target detection costs will rise with salaries.

It has been claimed that when multiple people perform the same task, each is less inclined to work to his full potential. To mitigate this possibility and help ensure each person's attentiveness, redundancy might be part time rather than full, and the onsite screener would not be informed when the task was being doubled.

In terms of who will be doing the screening, detailed recommendations as to the qualities sought in a screener have been described (Bolfing et al. 2009). But we found that age, gender, and experience were of low importance in comparison to real-time cognitive factors in making visual mistakes. Thus, a wide range of screeners will be able to be aided by a system with artificial event response.

CONCLUSION

Real-time target detection accuracy drops when the target is seen too infrequently, or when the person is distracted by a task other than target detection. We explain that the drop in accuracy occurs because the target was seen but not remembered. Therefore, we propose a solution to create artificial threats of the same nature as the actual threats so as to firm the events in memory, and heighten the expectation for seeing similar threats that are real.

Our experiment corroborated the effect of prevalence in reducing inattentional blindness as had been found by other researchers. We went beyond other prevalence research in proposing a method to test whether there is an optimal artificial event frequency to improve target detection effectiveness, and we showed how this question could be answered quantitatively.

We proposed that continued use of an interactive artificial event response system in daily operations such as surveillance monitoring could lessen the number of misses that are inevitable due to inattentional blindness. The interactivity would be the user response to the artificially-inserted targets; the system intelligence would be the system recording of user responses as to target type and screen location, and then typing and locating artificial targets so as to raise user awareness. The proposed system could be used in conjunction with non-automated covert testing, if appropriate. Another route to improving target detection would be to add staff to insure viewing redundancy. A similar practical approach could be applied to other domains such as medical slide or X-ray screening.

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