Effects of Stress and Distraction on Operator Performance

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***Abstract*—Loss of situation awareness is often cited as the cause of disasters involving operators of complex systems. This can occur not only because of high stress situations but also because of boredom during low stress situations. We report on a study in which participants are given a repetitive computer-based task to perform and measured their level of performance as a result of stress and distractions. While some of our results were compatible with the Yerkes-Dodson Law, most were not. We also found that how one measures performance and stress have an impact on what one observes. The research on the Yerkes-Dodson Law and our study suggest that reducing the cognitive burden on the operator may in some cases actually be counter-productive because of the possibility of boredom.**

Keywords: situation awareness, stress, boredom, cognitive overload

I. Introduction

Loss of situation awareness is often cited as the cause of disasters involving operators of complex systems. This can occur not only because of high stress situations but also because of boredom during low stress situations. This article reports on the results of a study in which participants are given a repetitive computer-based task to perform and measured their level of performance as a result of stress and distractions.

II. Related Work

It has been known at least since 1908 that increasing arousal or stress levels do not necessarily result in decreasing performance levels. This observation is known as the Yerkes-Dodson Law which is described as being a bell- or inverted-U-shape [1]. A consequence of this law is that optimum performance occurs at an intermediate level of stress or arousal. It was also observed that the shape of performance curve varies depending on the task being performed and as a result the optimum stress level varies with the task. Low levels of performance at high levels of stress are usually interpreted as being due to cognitive overload, while low levels of performance at low levels of stress have been interpreted as being due to boredom [2]. Unfortunately, there does not seem to be a generally accepted definition of the notion of boredom. So attributing the low levels of performance at low levels of stress to boredom is not well defined. Nevertheless, the phenomenon has an empirical basis whatever the cognitive basis for it might be.

A Rand Corporation report by Kavanaugh reviewed the literature on the phenomenon with particular applicability to the performance of military tasks [2]. A biological basis for the phenomenon has been proposed in [3]. Recent US Navy ship collisions have highlighted the importance of boredom as a contributing cause for the disasters [4]. Modern airliners are now so automated that the pilots have little to do during a flight. Unfortunately, in one case the pilots overshot their destination by hundreds of miles because they had stopped paying attention to the flight.

Most work on computer games seems to be concerned with enhancing player enjoyment. This is not surprising since the objective of most computer game companies is to sell games. Some computer games have other objectives such as education, which is also not closely related to our concerns. Aircraft and other kinds of simulators are more closely related to the purposes of our study. The Operator Performance Laboratory (OPL) at the University of Iowa is an excellent example of research of this kind [5]. The focus of this laboratory (as stated on their website) includes neurally inspired interfaces, Cognitive Avionics, synthetic and enhanced vision, flight test research, flight simulation, pilot eye movements, pilot and crew performance and workload, upset prevention and recovery, situation awareness assessment, and display optimization research. The laboratory also studies ground transportation in similar ways. While this work is valuable and they have published extensively, we did not find any work that used internal software behavior as a means of monitoring the operator.

The OPL approach to monitoring operator performance is to use biomedical sensors, such as pilot eye movement monitors. While the research of the OPL is certainly very important, biomedical sensors are invasive, not all operators would be comfortable with them, and some may not even permit them. Many automobile drivers, for example, would object to such sensors. Moreover, even if the operator permitted such sensors, the fact that one is being observed could affect performance. This is known as the “observer effect” and is well known in sociology [6].

The observer effect is, in fact, a very general phenomenon as noted in [6]. The basic technique for analyzing observer effects is to combine the observer and the system being observed into a single system. One of the motivations for our research was to treat the operator as being part of the system rather than being outside the system.

III. Materials and Methods

The study used human subjects. All subjects were Northeastern University students who were at least 18 years old. There were no other exclusions. The subjects were required to play a computer game on a computer that we provided. Although the total time commitment could have been up to one hour, in practice it never took more than 30 minutes. Each student was paid $10.00. Students were told the purpose of the study. The sessions were double-blind: neither the subjects nor the experimenters knew which experimental group the subject was in. All of the experimenters passed the NIH Web-based training course "Protecting Human Research Participants". The Northeastern University Institutional Review Board approved the study.

The study used a computer game similar to Tetris. The objective is to continue playing the game as long as possible. However, it was unlikely that any of the participants would have had prior experience playing the game. Figure 1 shows what the game looked like to the participants. The purpose of the game was to defend a position against attackers, such as tanks and helicopters. The score of a game was based on the number and type of attackers that were destroyed. However, the score was not used in the analysis.

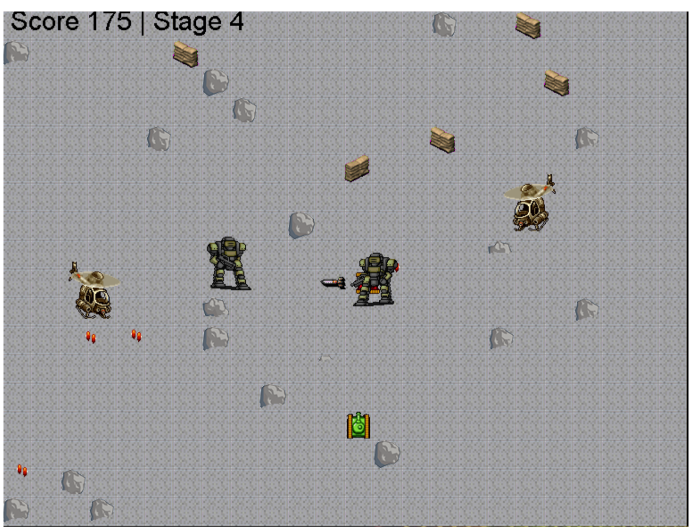

Fig. 1. One frame from the computer game

As in games like Tetris, the game can be made more challenging by increasing the speed. In our game, it was controlled by frame rate. This is the number of frames per second that were shown to the participant. A slow game was shown at 30 frames per second, while a fast game was shown at 50 frames per second.

Some participants were also distracted by popup windows that had to be answered before the participant could continue defending the position. Distractions occurred at random times and random locations on the screen. A participant either had to contend with distractions or had not distractions.

To furnish a baseline for the behavior of the game software, we recorded some games in which no attempt was made to defend the position. These games ended relatively quickly. They were marked as having "no active player" and had no distractions as that would have required a participant to be involved.

In addition, 6 participants played at a speed intermediate between slow and fast. These participants were not used in the analysis.

The following were the experimental groups:

- Slow speed with no active player
- Slow speed with no distractions
- Slow speed with random distractions
- Fast speed with no active player
- Fast speed with no distractions
- Fast speed with random distractions
- Accelerated speed with no distractions

Performance for one game was measured in two ways:

1) Endurance. The amount of time that the subject succeeded in defending the position.
2) Productivity. The number of frames during which the subject succeeded in defending the position.

The following data was recorded for each game that was played by a participant:

- Participant Identifier
- Duration of the game in milliseconds
- Frame Rate in frames per second
- Had Distractions (true or false)
- Active Player (true or false)
- Had Pause (true or false)
- Score

Some games were interrupted by a pause for a unrecorded amount of time. These games were not included in the analysis but were recorded in the database.

The database is available as a CSV file upon request. It has 5261 records of which 4609 represent games played by a participant and 652 did not have an active player. There were 119 subjects of which 114 were used in the study. They were randomly placed in the groups which resulted in the following distribution:

- Slow speed with no distractions (30 participants)

- Slow speed with random distractions (30 participants)
- Fast speed with no distractions (26 participants)
- Fast speed with random distractions (28 participants)
- Accelerated speed with no distractions (5 participants)

The main comparison was for the endurance and productivity at slow and fast speeds as well as with and without distractions. The Welch t-test was used for this purpose. In addition, a linear model, using least squares, was found for each participant.

IV. Results

The results of the Welch t-tests were as follows. In Table I, all games played at slow speed are compared with all games played at high speed. When performance is measured using endurance, the fast games have significantly lower performance. The added stress signficantly reduces performance from this point of view. However, the reverse is the case in the second row of the table. Measured by productivity, the fast games have significantly higher performance.

TABLE I
Comparison of slow versus fast games with one-sided tests

	Slow Games	Fast Games	p-values
Endurance	34.0 sec	25.0 sec	2.08×10^{-9}
Productivity	1019 Kframes	1249 Kframes	5.34×10^{-5}

Next consider the effect of distractions. The results are shown in Table II. For both ways of measuring the performance, having distractions reduces performance significantly.

TABLE II
Comparison of games without and with distractions using two-sided tests

	Without Distractions	With Distractions	p-values
Endurance	30.9 sec	26.9 sec	8.6×10^{-3}
Productivity	1198 Kframes	1065 Kframes	0.027

The next comparisons split the slow games into two groups for with and without distractions, and similarly for the fast games. This differs from Table I in which all of the slow games were compared with all of the fast games. The p-values are shown in Table III.

TABLE III
Grouped comparisons of slow versus fast games with two-sided tests

	Without Distractions	With Distractions
Endurance Slow	36.6 sec	31.5 sec
Endurance Fast	27.1 sec	23.2 sec
Endurance p-value	3.87×10^{-5}	8.99×10^{-6}
Productivity Slow	1097 Kframes	946 Kframes
Productivity Fast	1356 Kframes	1162 Kframes
Productivity p-value	2.39×10^{-3}	2.48×10^{-3}

A similar splitting into groups can also be done for distractions, but none of these were significant, so they were not shown.

Finally, the least squares linear models had the statistics shown in Table IV for participants who played slow games and in Table V for participants who played fast games. It appears that the performance of participants who played slow games decreased over time for either measure of performance and that the reverse is true for participants who played fast games. This is compatible with the interpretation that participants who played the slow games were getting bored while the reverse was the case for participants who played the fast games. However, the ranges and variances of the slopes are very large, so these are not statistically significant results.

TABLE IV
Average Change in Performance for Slow Game Sessions

	Minimum	Mean	Maximum	Unit
Endurance	-17.35	-0.682	29.99	sec/game
Productivity	-520	-20.5	900	Kframes/game

TABLE V
Average Change in Performance for Fast Game Sessions

	Minimum	Mean	Maximum	Unit
Endurance	-15.6	0.374	32.99	sec/game
Productivity	-778	18.7	1649	Kframes/game

V. Conclusion

The study results are compatible with the Yerkes-Dodson Law when stress is determined by the frame rate and performance was measured using productivity. However, when performance was measured using endurance, the performance decreased with increasing stress. While we did not examine enough stress levels to determine whether the Yerkes-Dodson Law failed to hold in this case, it does appear that how one measures performance is important. We also found that distractions reduce performance however it is measured. Again, we did not examine enough distraction levels to determine whether the Yerkes-Dodson Law failed to hold in this case, but it also appears that the kind of stress and how it is measured are important. This suggests that the relationship between stress and performance is more complicated than a naive interpretation of the Yerkes-Dodson Law would suggest.

Another observation is that performance seems to improve or deterioriate on average. Those who played slow games seem to be gradually getting more bored, while those who played fast games seem to be gradually performing better, but the variance was too large for this to be significant.

Our experiments also suggested that the relationships between various forms of stress and various measures of performance are more complex than one might expect.

VI. Future Work

Although our study found many significant results, the experiments did not have sufficient power for answering all of the questions that were raised. In particular, the dependency of performance on stress and distraction was determined at only two levels. A larger number of levels need to be examined to determine the precise functional characteristics for different forms of stress and distractions. In addition, more measures of performance beyond just endurance and productivity should be considered. For example, various ways of scoring and grading are also measures of performance.

The results of our study were characteristics of groups of individuals. No single individual was exposed to more than one stress or distraction level. The dependency of performance on stress and distraction for a single individual is also important. Although we did exampine this to a small extent, much more would be needed to determine the degree of variation among different individuals.

The possibility that individuals progressively become bored or overloaded over time will also be studied in more detail. This will require participants to engage in an activity over a longer period of time than was done in our study.

While the computer game we used in our study was effective for discovering interesting results, it had a great deal of randomness. As a result, there was a great deal of variance which prevented answering some of the questions. Accordingly, we will design a new task for the subjects to perform that will have less random behavior, which should reduce the variance of the statistics and improve the power of the tests.

VII. Acknowledgments

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