A Method to Represent the Effect of Training on Stress

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ABSTRACT

Stress is the internal response to the stimuli that challenges an individual's ability to cope. Nowhere is ability to cope more important than on the battlefield. The inclusion of stress in Semi-Automated force simulation can enhance the realism and fidelity distributed simulation training experiments. The ability for soldiers to cope with the stress of battle can be enhanced through training.

In current combat simulation, stress and the factors that affect it are not well represented. Stress is theoretically understood but there are few mathematical models that can be used for operationalizing the theories into analytical simulations.

Current theory on stress uses the inverted-U curve to show how the relationship performance changes with the increase of stress. The relationship also states that there is an optimal range of stress, where individuals attain the range of physiological, emotional, and cognitive mobilization which best enables them to accomplish their purpose. Training increases the optimal range of stress, allowing an individual to handle more stress before decreasing performance. It is theorized that a mathematical model can be produced to represent this relationship. This model can then be used to represent simulated individual stress-coping and to investigate how measures of performance are affected in a given experiment.

This paper will define the stress/performance relationship, the effect of training on this relationship, and provide a mathematical function to represent this effect. Finally, a proposal will be made to use this mathematical function to represent stress and the effect produced by training in distributed semi-automated forces simulation

A model that represents stress can significantly enchase Semi-automated forces. Simulated soldiers will have the ability to react in a more realistic manner and provide future "real" soldiers with enhanced training simulations and have far-reaching implication on the study of stress on the modern battlefield.

ABOUT THE AUTHOR

Dr. William Warner is an Engineer in the Engineering and Analysis Operation, Systems and Technology Solutions Business Unit, SAIC. Dr. Warner supports the Cross Command Collaboration effort for sharing modeling and simulation assets and information across the US Army training, engineering and development commands. Dr. Warner has over 10 years experience in the modeling and simulation field working on a variety of modeling projects, such as new aircraft carrier flight deck operation model and the psychological impact of submarine manning and new control room designs. Dr. Warner received a PhD in modeling and Simulation from Old Dominion University in 2006. Dr. Warner also holds a Masters of Engineering in Modeling and Simulation and Bachelors in Mechanical Engineering Technology.

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INTRODUCTION

The importance of understanding stress as it affects an individual's performance is well documented. Yerkes and Dodson (1908) stated that stress influences arousal, which in turn influences performance. The Army Field manual NO. 22-51 (the leader's manual for combat stress control) describes the opposite end of the effect of stress on a soldier's performance. It states that if there is too little arousal, the job is done haphazardly and when arousal is extreme the soldier may freeze or flee in panic.

This relationship between stress and performance has been identified as an accepted casualty-causing phenomenon. Grossman (2004) describes how stress debilitates more warriors than are killed in direct hostile action. Today's military planners need to understand the nature of stress to minimize its adverse impact.

Stress is a part of everyone's daily life. It is a biological reaction to situations perceived as possible change in an individual's current state. It can be seen as a threat against an individual's safety or as challenging and energizing. These changes are due to physical stressors such as noise, heat, or trauma; or psychological stressors, such as fear of the unknown or life events.

An individual who is under the influence of a stressor will go through three stages of adaptation. First is the alarm reaction, which can be generalized as a call to arms for the defensive forces form an individual. Second is the stage of resistance, in which an individual's biological systems begin to try to adapt to the stressors' influence. Finally after a prolonged exposure comes the stage of exhaustion when the body creates a situation that makes the individual want to end the condition by any means necessary.

As well as stressors, there are such things as stress mitigators. Training, unit cohesion, or familiarity with a successful situation can reduce the effect of stress and delay the exhaustion phase. This allows the individual to resist longer and maximizes the performance of any task in which they are involved.

It is believed that of all the stress mitigators, training has a demonstrable effect on the ability of an individual to react to stressors in the environment. Training gives the individual soldier confidence, but even more, an awareness of how stress works in oneself and others. It teaches stress control, not stress reduction.

In light of the effects of stress on an individual it has been recognized that the ability to control their stress is most useful in an environment such as a battlefield. Integrating stress and its effect would be a useful addition to any training program.

One of the fastest growing fields in the training arena is the field of modeling and simulation. Realistic behaviors need to be included into live, virtual, and constructive (LVC) simulations so that the individual who is experiencing the exercise can increase his/her stress control to the applied scenario.

Models of automated forces used in the LVC environment need to have realistic representations of stress reaction. This is so that soldiers being trained by simulations using such models can prepare them for the real battlefield. The soldier needs to be trained with computer generated friends as well as foes so that they experience behavior that is as possible to get maximum benefit from the simulations.

The representation of stress on the LVC battlefield is an emerging field of study. Usually arbitrary factors are applied as to simulated forces to represent unit stability or breaking points. These may not be sufficient to show the wide breadth of human reactions to stressful situations. They do not explain why one soldier stands while another flees. This paper will propose a first small step in creating models of individual stress reactions, but will hopefully provide a framework from which all stress factors and moderators can be represented and eventually incorporated into the LVC environment.

The remainder of this paper will describe existing models of stress, the effect training has on that relationship, and propose a mathematical function that will allow the modeling of the stress-performance relationship. A specific example will be presented to support the proposed mathematical function and finally the implications of this tool for the future research into modeling stress and is components.

A MODEL FOR STRESS REPRESENATION

Yerkes and Dodson introduced in 1908 the much discussed Yerkes and Dodson Law, which states that the relationship between arousal level and performance may be expressed in the form of an inverted-U (see figure 1). The law also states that the optimal level of arousal for performance is inversely related to the task difficulty (Matthews et. al. 2000).

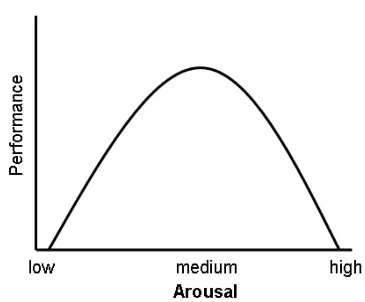

Figure 1. Yerkes-Dodson Law

This relationship can be explained by the psychophysiological reactions an individual experiences during a stressful situation. As the body reacts to a stress stimulus, the individual enters the alarm reaction stage. The heart begins to pump harder as hormones arouse the sympathetic nervous system. The heart rate will continue to rise until the adaptive stage is reached and hormones produce the optimum level of physical conditions for performing a task. The optimal stress level is the range of stress arousal that enables an individual to accomplish the task.

If the stress situation continues, the blood begins to flow faster through the body and the oxygen exchange rate begins to deteriorate. This causes loss in cognitive processing, depth perception, complex motor skills. The individual then enters the exhaustion stage and performance drops.

Training affects this sequence by shifting the optimal stress level to the right (see figure 2), thus allowing an individual a greater range of stress in which the adaptive stage can exist (Matthews et. al. 2000). This is because the easier the task, the less stress it will cause. Training makes the task easier as the individual gains familiarity and feels more capable of its accomplishment.

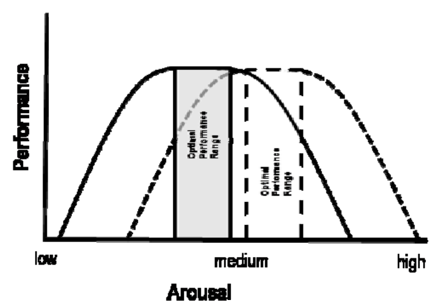

Figure 2. Effect of training on the Yerkes-Dobson Law

David Grossman (2004) presents the Yerkes-Dobson Law curve as a base normal function across the range of no stress to the maximum possible stress an individual can endure (see figure 3). Since any individual's physical makeup can vary, the curve representing the stress reaction may vary throughout a wide possible range.

This curve, if scaled to a stress level indicator and a measure of performance could be used to develop a function that would calculate a multiplier used to determine how well an individual could accomplish a task given that a particular level of stress is being experienced.

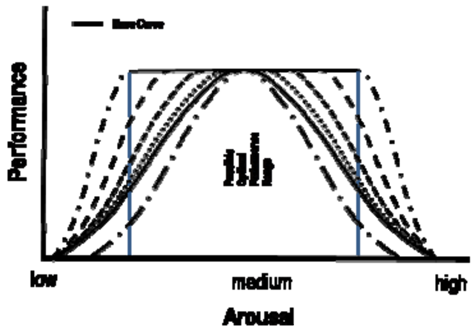

Figure 3. Variations on the Yerkes-Dobson curve

The next section of this paper will define such a function and show how it can represent the Yerkes-Dobson relationship with training of an individual.

THE STRESS-PERFORMANCE FUNCTION

After understanding the Yerkes-Dodson law relationship, it is necessary to ask if there is a way to create a computational model that can be used for simulation. What is needed is a function that will allow an individual to change from the alarm reaction, transition to an adaptation state and transition again into an exhaustion state as seen in the GAS and in the Yerkes-Dodson law.

This work suggests that the double-sigmoid function can be used to represent the Yerkes-Dodson law because the double-sigmoid is used in the modeling of neural and cognitive brain functions. D. Levine (1991) describes the need to average brain responses to model the random nature of neurons transmitting information during strenuous mental activity. The output of such activity is a sigmoid function. Levin (2005) uses the sigmoid functions to model brain mechanisms of the gross modes of behavior labeled fight-or-flight.

Sigmoid functions are produced by a mathematical function having an "S" shape. This function is used when there is more than one state of transition in a system response. When two transitions of state need to be represented, the Double-sigmoid function is used. The function can be seen in equation 1.

$$f(y) = \frac{a}{1+\exp\left(\frac{x-b+\frac{c}{2}}{d}\right)}\left[1-\frac{1}{1+\exp\left(\frac{x-b-\frac{c}{2}}{e}\right)}\right] \quad (1)$$

A more general function is needed for real world fits to natural phenomena This can be achieved by using the simpler and computationally better hyperbolic tangent function version of the double-sigmoid function which can be seen in equation 2 (Roper 2002).

$$f(y) = \frac{1}{2}\left[\tanh\left(\frac{x-c_1}{w_1}\right) - \tanh\left(\frac{x-c_2}{w_2}\right)\right] \quad (2)$$

In this equation, x represents the arousal level due to stress, c represents the inflection point of the curve, and w is the width or steepness of the curve. When a range of values is input for x, assuming some value for the variables c_1, c_2, w_1 and w_2 which represent characteristics of a system; the graph in figure 4 is produced.

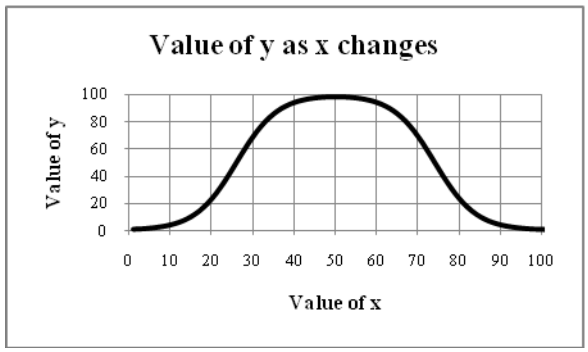

Figure 4. Graph of the double sigmoid function

The utility of the double-sigmoid function is that by manipulating the values of c_1, c_2, w_1 and $w_{2;,}$ the shape of the curve can be altered to fit experimental data.

The value of c_1 determines the inflection point of the left hand curve. C_2 is the inflection point of the right hand curve. The w_1 and w_2 determine the steepness of the respective curves (see figure 5).

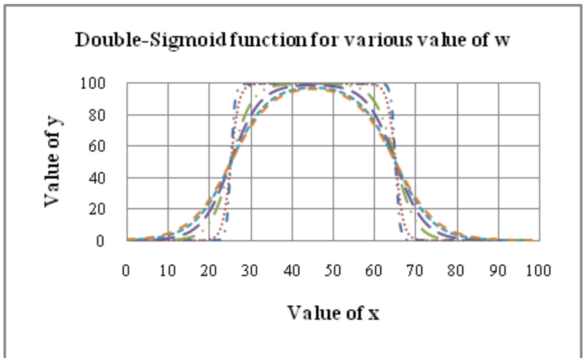

Figure 5. Double-Sigmoid function for various value of w

When the values of the variable c_2 are manipulated, the right side of the curve moves to the right. This produces the result as seen in figure 2. This can represent the increased performance as the individual is trained and can operate with a larger range of stress (See figure 6).

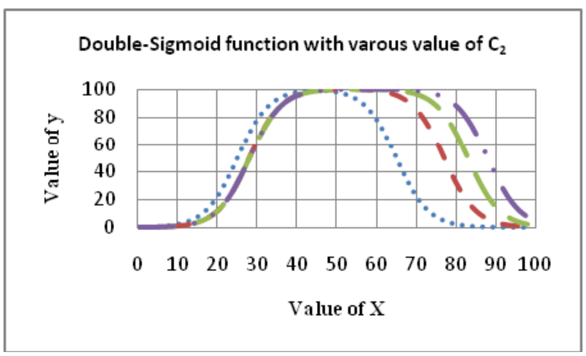

Figure 6. Double sigmoid function for various values of c_2

Now that the phenomenon has been explained and a method to represent it has been established, an example can be presented to exemplify the premise of this work.

AN EXAMPLE OF THE DOUBLE-SIGMOID FUNCTION MODEL

Since the use of the Double-Sigmoid function is a new idea, there is no empirical data to exemplify its use. However, this example can be presented to show the utility of the function to represent the Yerkes-Dodson law and the effect of training (on what?).

First, a measure of stress needed to be defined. According to Alluisi and Fleishman (1982), heart rate is the most popular of the physiological measures used in studies of performance. Lacey (1974) has shown that attention to the environment produces changes in an individual's heart rate. This change in heart rate accompanies changes in the performance, particularly in task that involve fast reaction times. There is considerable debate on the use of heart rate alone to measure stress however; LeDoux's post-1995 research shows that heart rate increase is a "thermostat" or "indicator" of a perceived stress level. For this example it is used to show the utility of the function and the debate over the stress indication of heart rate is left to other publications (Laur 2002).

Grossman (2002) lays out a scale for the psychophysiological effect that can be correlated to heart rate. He set the average optimal performance heart rate as 115 beat per minute (bpm) to 145 beats per minute. This will be the adaptation range for the example curve.

Using equation 1 we make the value of x to be the heart rate. This will be and indication of the stress an individual's perceives. The range for the heart rate is set at a minimum of 60 bpm, which is the lowest average heart rate for a healthy human being (Grossman 2002) and a maximum of 220 which is the highest heart rate a human can attain before cardiac failure (Grossman 2002). To fit the heart rate correctly to the curve the average of the range will be subtracted from the raw heart rate. If this is not done the values on the left hade curve will be negative and the curve will straddle the value of 0 instead of the middle point of the range. The C_1, C_2, W_1 and W_2 are defined as some experimental value curve of an individual's reaction time for some task.

$$RT = \left[tanh\left(\frac{(HR - Avg) - c_1}{W_1}\right) - tanh\left(\frac{(HR - Avg) - c_2}{W_2}\right)\right] * SF \qquad (3)$$

In equation 3, *HR* represents the heart rate; *RT* is the value for reaction time, or some other measure of performance, and *SF* a scaling factor. Since this example is not based on empirical date, scaling factor has been added in order to make numbers fit this hypothetical example. The scaling factor should be adjusted to the maximum measure of performance.

The value for C_2 is the variable that will move the curve to the right, and it represents the increase range of heart rate that an individual will be able to attain given some amount of training.

For this example the variables C_1, W_1 and W_2 are set to 40, -10 and -10 the scaling factor will be set at 100. The average value for given range is 139. This will give Equation 4.

$$RT = \left[\tanh\left(\frac{(HR - 189) - 40}{-10}\right) - \tanh\left(\frac{(HR - 189) - c_2}{-10}\right)\right] * 100$$
(4)

If the range of 60 to 220 is input into the equation, with an initial value of 25 for C_2, the solid curve in figure 7 will be produced. This figure shows the appropriate range of optimal performance for the given curve. If the value for C_2 is increased to 40 the dotted curve is produced, with it appropriate optimal performance range.

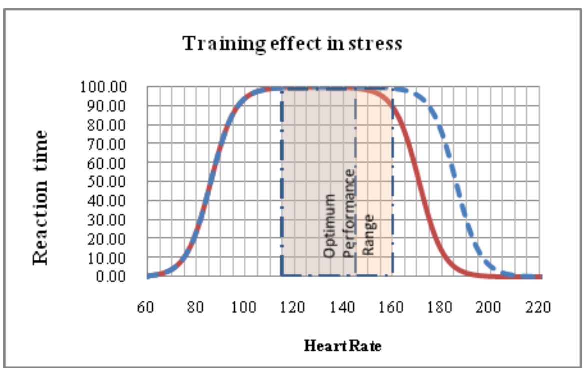

Figure 7. Example Graph

This equation can now be used to represent an individual's reaction time base on the observed reactions of the stress he/she perceives. It might be useful in creating a numerical range (e.g., training time) that would increase the optimal performance range.

Conclusion

The ideas presented in this paper present a beginning. There is more that needs to be looked into for a full definition of the function that would model the interaction of stress and an individual's environment. Effect such as fatigue, physical injury confidence, experience will need to studied and incorporated into the double-sigmoid function presented here.

It has been shown that the double-sigmoid function can represent a Yerkes-Dodson curve and the effect he that training has on such a curve. The flexibility of the function can take into account the variability from individual to individual and has the possibility to represent other aspect of the human stress reaction. What needs to be done is to have an empirical experiment where an individual's stress is measured during a task and that stress is graphed using the double-sigmoid with any appropriate scaling functions. After a controlled training period, the stress can be measured and plotted again using the double-sigmoid function. This will make it possible to fully analyze the utility of the function and to see if it can be adequately used to enhance the representation of psychology in the realm of military combat models.

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