# Stress Training Efficacy in an Aviation Context

Christopher K. McClernon

# STRESS TRAINING EFFICACY IN AN AVIATION CONTEXT

Christopher K. McClernon
The MOVES Institute, Naval Postgraduate School
Monterey, CA

Stress is regularly introduced in training to prepare troops for stressful environments and situations, although there is very little empirical evidence for stress training's effectiveness, implementation and pedagogy. Twenty novice participants were recruited and assigned to either a stress-trained (cold pressor), treatment group or a control group. Stress training was effective at improving the treatment group's performance during a final criterion session on an aircraft navigation task compared to the control group. In addition, the stress-trained group showed lower criterion heart rate variability, skin conductance, and subjective stress ratings compared to the control group. This research demonstrates stress training as a viable approach for preparing military members for stressful flight environments and combat, in general. Further research addressing the generalization of these results to novel, real-world stressors is proposed.

Stress is often introduced in training so that real-world stress is more familiar and easily mitigated. Stress training relies on transfer-of-training research including Osgood's (1949) similar elements theory, indicating that training should share elements with the transfer task in order for the training to be effective, or as the military often refers to as "train how you fight". Therefore, to train for a stressful task, a stressful training environment is often utilized in the military. Stress training also relies on Overton's (1964) state-dependent learning where retention and retrieval is dependent on a person's emotional, physiological, and mental states during both training and recall.

A notable component of training pedagogy is Driskell, Johnston, and Salas's (2001) reference to structural and surface features. In an attempt to explain the generalization of stress training to various transfer stressors, they go beyond Thorndike and Woodworth's (1901) identical elements theory to emphasize the features relevant to both the training and transfer tasks. Structural features refer to "the underlying principles imparted in training," while surface features refer to "domain-specific characteristics, such as the specific training examples used and the specific attributes of training context" (p. 108). For example, in an aviation context their research suggests that a pilot will benefit from stress training even if the context (surface features) for which he received the stress training (i.e., a low-fidelity flight simulator) is different from the transfer task (i.e., an aircraft). In this case, the stress training itself is thought of as a structural feature, and in their study "it is likely that the stress training resulted in positive transfer to novel settings [and novel stressors] because the underlying principles in training were structurally consistent with the transfer environment" (p. 109).

## Stress Training

Stress occurs when "the perceived demands of a situation tax or exceed the perceived resources of the system (individual, group, community) to meet those demands, especially when the system's well-being is at stake" (Lazarus & Folkman, 1984, p. 8). Early stress researcher Hans Selye (1974) proposed that there are three different responses to environmental stressors. First, from a biological standpoint, an organism can exhibit a catatoxic response to stressors in which a fight response attempts to actively eliminate a stressor. This response can be either impossible or very taxing on an organism. In a combat context, fighting peripheral stressors (e.g., heat, radio noise, ambushing enemy troops, etc.) often distracts from the operational mission. A second response to stressors is the flee response in which an organism attempts to remove itself from a stressor. Again, in a combat context, this response is typically infeasible short of retreat. Finally, and often the most plausible response to stressors as defined by Selye, is a syntoxic response in which an organism learns to co-exist with stress. It is this coping mechanism which allows an organism to exhibit goal-seeking behaviors in the presence of stressors--this behavior is most favored in a combat setting and is the premise for this research endeavor.

Stress can have a profound effect on performance which is demonstrated by the Yerkes-Dodson Law (Yerkes & Dodson, 1908). An optimum amount of cortical arousal corresponds to the highest performance for a given task. Further, as more stress is introduced, resulting in heightened arousal and an appraisal of more demands than resources, performance will deteriorate. The same is true for low levels of stress (and associated lack of arousal) in which boredom and/or complacency can result and performance suffers again. The Yerkes-Dodson Law

*The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.*

is also task dependent; simple cognitive tasks, which may insinuate relatively low attention and cognitive requirements, may be subject to higher levels of stress before optimum cortical arousal is achieved, and vice versa. Finally, the Yerkes-Dodson Law is subject to individual differences, where novices may be quickly inundated with stress, while experts may not only successfully moderate the effects of stress but they may *require* higher levels of stress to prevent complacency and optimize performance. Individual differences can also refer to innate personality characteristics and coping strategies employed by different people.

In an attempt to alleviate individual workload and stress many attempts have been made to introduce automation, technologies, intuitive controls/displays, etc. However, these approaches are often very costly, have theoretical limitations, and, in some cases, can actually increase stress. Another approach to alleviate stress in which a dearth of research exists is stress training. However, introducing stress training can often result in two counterproductive results: (1) high levels of anxiety which inhibits both training and post-training performance, and (2) stress which interferes with the acquisition of skills and knowledge for which the training is designed to promote (Friedland & Keinan, 1992). Friedland and Keinan present three stress training approaches in an attempt to (1) effectively impart skills and knowledge on trainees, (2) expose and inoculate trainees to real-world levels of stress, and (3) alleviate the before mentioned shortcomings.

First, a graduated-intensity approach to stress training attempts to slowly "inoculate" trainees with a progressive training protocol while theoretically not impeding task acquisition. While graduated-intensity training can provide trainees with a heightened sense of control and competency, the gradual introduction of stress can breed unrealistically low expectations about transfer task stress levels. Another potential approach to stress training is adapting the training to an individual's needs. By tailoring stress training to each individual, a training system can ensure that both appropriate levels of stress exposure and criterion performance are met, independent of time in training. However, this method relies on the trainee's subjective perception of resources, and may not always indicate proficiency for the task at hand (Friedland & Keinan, 1992). A final training approach that has shown the most promise for alleviating stress while ensuring the acquisition of skills is by following a validated three-phase approach to stress training. Friedland and Keinan defined and tested the interplay between three elementary phases of training: task acquisition (TA), stress exposure (SE), and practice under stress (PUS). They found that introducing stress training in this order resulted in the best performance in a criterion task. These findings indicate that a phased approach to stress training is both effective and efficient. In addition, task acquisition is of foremost importance in any training program; without the proper development of skills, transfer performance will certainly suffer. Lastly, complete compartmentalization of stress exposure or skill acquisition (e.g., exclusion of the PUS phase) is insufficient--both the task and stress exposure must be integrated into a total training plan.

Johnston and Cannon-Bowers (1996) provide further guidance for Stress Exposure Training (SET) which evolved from three main objectives: building skills that promote effective performance under stress, building performance confidence, and enhancing familiarity with the stress environment. Not unlike SET, stress inoculation training (SIT) is a phased training approach in a mostly clinical context, although there are many potential applications of SIT for the training of stressful tasks. As Meichenbaum (1993) points out, the primary notion of SIT is that "bolstering an individual's repertoire of coping responses to milder stressors can serve to defuse maladaptive responses or susceptibility to more severe forms of distress and persuasion" (p. 378). Both SET and SIT consist of three phases, congruent to Friedland and Keinan's three phases.

In a meta-analysis of 37 studies testing the effectiveness of a three phased approach to stress training (i.e., SET or SIT), Johnston and Cannon-Bowers (1996) determined that 67% of studies demonstrated that stress training significantly improved performance. In their meta analysis, Saunders, Driskell, Hall, and Salas (1996) determined that stress training was effective in reducing performance anxiety, reducing state anxiety, and enhancing performance under stress. Despite these findings, no research addresses the applicability of stress training to a stressful flight environment.

## Methodology

A study was developed to test the efficacy of a three-phased training approach in an aviation context. Unlike previous research which used a very short-term stressor (e.g., 15 seconds; Friedland & Keinan, 1992; Rosenbaum, 1980), a longer acute stressor (10-15 minutes) was introduced--this is more congruent with aviation and/or combat stressors. In addition to performance measures, human physiological responses and subjective appraisals were used to evaluate the efficacy of stress training in this context.

*Participants.* Twenty participants (16 males, 4 females) were recruited and ranged in age from 25-39. All participants were required to have 20/20 corrected vision and no known health ailments. In addition, none of the participants had any flying experience.

*Equipment.* The virtual environment (VE) consisted of 1 desktop computer, 1 visual display, a flight yoke control input, and an audio headset. The only control input for the simulator was a Precision Flight Instruments Cirrus yoke. The rudder (yaw) controls were coupled to the yoke and the throttle was set at a constant setting by the experimenter. This was to limit the amount of training required before testing the applicable research questions.

Trials took place in the X-Plane® v8.0 flight simulator using the included Cessna 172 flight model and instrument panel. The simulator outside view was replaced with instrument meteorological conditions (i.e., visibility less than three nautical mile) and the aircraft display was limited to only three instruments: attitude indicator, altimeter, and directional gyro. Simulator audio output consists of the simulator audio feedback (i.e., engine and wind noise), air traffic control instructions (i.e., *clearances*), air traffic background "chatter", and experimenter/participant voice. The physiological data collection equipment consisted of the Thought Technologies Ltd. ProComp Infinity™ Biofeedback System using both electrocardiogram (EKG) and Skin Conductance (SC) sensors. The BioGraph Infinity 4.0® software was used to collect and analyze the physiological data.

*Stressor.* The stressor was a cold pressor similar to Friedland and Keinan (1992) and Rosenbaum (1980). The cold pressor method consists of submerging the participant's foot in a bucket of ice water kept at a constant 9°C. This method applied to the hand has proven to effectively introduce stress without harming participants--given the hand dexterity required for this task, the pressor was applied to each participant's left foot. A pilot study determined that this stressor interacted with the primary task and reliably affected physiological responses to stress without undue discomfort to the participant.

*Task.* Following an administrative portion, participants received training on flying the aircraft from a licensed pilot. They were first taught the functions of the three instruments and the control yoke. They were then taught strategies for flying straight and level, turning, climbing, and descending. Following an instructional video, participants were then given time to practice these procedures. Following training, both control and treatment groups performed a TA session consisting of turns, climbs, and descents to provided clearance headings and altitudes (see Figure 1). A pilot study determined mean times to asymptotic performance during this session which determined the length of this and subsequent sessions.

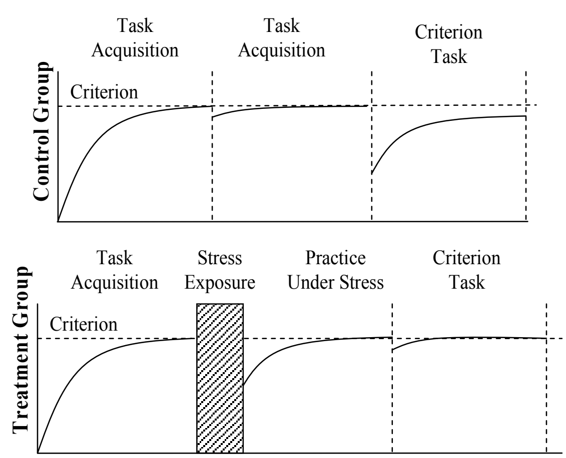


*Figure 1.* Experiment schedule

Next, the treatment group received stress exposure, separate from the task, where stress mitigation strategies were practiced. The treatment group then performed the flying task while exposed to stress and the control group performed a second TA session to control for the amount of time both groups received in the simulator. Finally, both groups performed a criterion session where the task `was performed during exposure to the stressor. Figure 1 shows hypothetical performance curves for control and treatment groups.

*Dependent Variables*

*Performance.* Flight simulator data was first parsed into maneuvering and straight/level portions of flight, and analysis was performed for both phases of flight. For maneuvering portions of flight, roll and pitch were used to calculate the root mean square error (RMSE) from the prescribed criteria (20- and 10- degrees, respectively). These two measures were then combined using a euclidean transformation ($\sqrt{x^2+y^2}$) to formulate a total measure of maneuvering error during each session. Likewise, for straight/level portions of flight, heading and altitude error from the provided clearances were calculated and combined in a similar manner.

*Heart rate variability.* While heart rate variability (HRV) is a time domain measure of the deviation between heart beat intervals, a power spectral density (PSD) defines the frequency content of this time-based stochastic process by performing a Fourier transformation of the time domain data. The PSD provides the ability to distinguish between different frequency spectra and associated *types* of vagal activity, or autonomic heart rate modulation. Physiological responses to stress often include an increase in LF power (LF; 0.05-0.15 Hz), a decrease in HF power (HF; 0.15-0.5Hz), and an increase in the LF/HF ratio (Berntson & Cacioppo, 2004; Pfieper & Hammill, 1995). Total very low frequency (VLF), LF, and HF power densities were computed as a function of baseline power for each maneuver and the total criterion session. Baseline measures were recorded during the instructional video.

*Skin conductance.* Another physiological correlate of human emotion is electrodermal response often measured using skin resistance, or "the electrical resistance of the skin to the flow of electromotive current and is measured in ohms" (Grossman, 1967, p. 504). The reciprocal of skin resistance, skin conductance (SC; measured in micro-Siemens, µS), is used to indicate autonomic nervous system activity, and, thus, allows inference regarding emotions. Unlike EKG, SC is a relative measure, meaning only an increase or decrease in individual SC relative to a baseline can indicate a heightened level of emotional arousal. Therefore, all SC measures were calculated as a function of each individual's baseline SC measure.

*Subjective stress ratings.* Subjective measures are often used as an indicator of human physiology. However, where physiology measures indicate the human body's response to a stress, subjective measurement provides insight about a person's appraisal of a situation given their available resources. Before each TA session, a sample query was conducted to determine each participant's baseline subjective stress level. Participants were asked, "Rate your current stress level on a scale from 1 to 10". Five times during each session, participants were again asked the same stress query. Each query was computed as a function of each participant's baseline.

## Data Analysis and Results

The experiment followed a between-subject design and each participant was randomly assigned to either the treatment or control group. An Analysis of Variance (ANOVA) was conducted on all performance, physiology, and subjective stress rating response measures with condition used as a predictor variable. An alpha level of 0.05 was used to identify any significant effect of stress training.

*Performance.* To account for individual differences, performance was computed as the mean criterion performance divided by each individual's asymptote performance during the final three minutes of the TA session (Cr/TAend). Stress training did significantly improve the performance of the treatment group for maneuvering portions of flight ($F(1,18)=4.43$, $p=0.049$) and total performance ($F(1,18)=4.87$, $p=0.040$; see Figure 2). Variability within each measurement was also collected and analyzed. A method pioneered by Mackie and Miller (1978), called the standard deviation of lane position (SDLP), measures the amount a driver weaves within a lane. For the purposes of this analysis, SDLP was used to determine how much a participant varied regardless of their assigned clearance. This variance measure showed no significant difference for altitude and heading (i.e., straight and level portions of flight; $p>0.05$). However, it did indicate superior treatment group performance when measuring differences in pitch ($F(1,18)=5.98$, $p=0.025$) and roll ($F(1,18)=5.18$, $p=0.035$) for the Cr/TAend measure (see Figure 3). These findings indicate the effectiveness of stress training to improving both precision and accuracy. This finding is not only pivotal for the current research, but it also provides evidence for the use of SDLP in an aviation context.

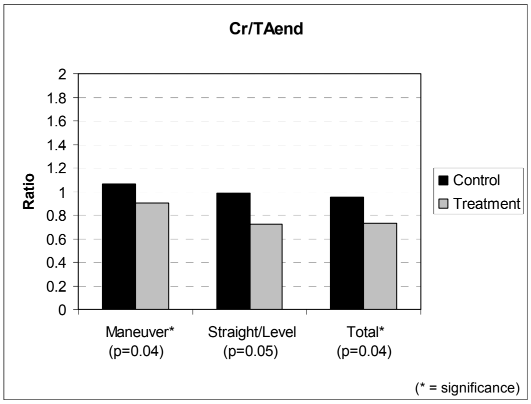


*Figure 2.* Mean criterion/asymptote RMSE

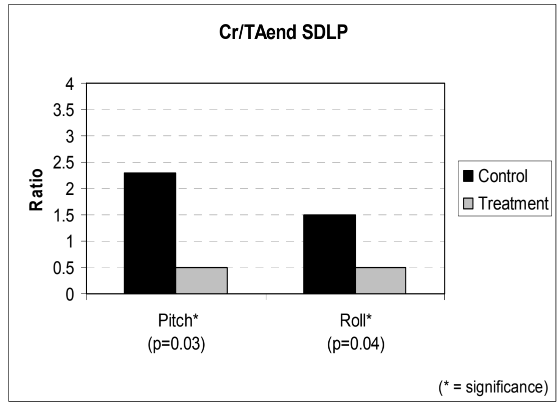


*Figure 3.* Mean criterion/asymptote SDLP

*Heart rate variability.* When comparing overall mean session HRV, an ANOVA determined that during the criterion session the control group had a higher mean LF PSD compared to the treatment group ($F(1,18)=7.74$, $p=0.012$). This indicates that the treatment groups' stress training significantly improved the participants' ability to mitigate the stress of the cold pressor in a stressful criterion task.

*Skin conductance.* After review of the SC data, one participant's data indicated erroneous conductance readings (~90 standard deviations from the group's mean SC). After removing this participant (N=19), ANOVA tests indicated no significant differences for the practice, TA, and TA2/PUS sessions ($p>0.05$), and a significant difference between groups for the final criterion session ($F(1,17)=4.61$, $p=0.047$).

*Subjective stress ratings.* As expected, analysis of the final criterion session revealed a significant difference between groups for the first ($F(1,17)=13.93$, $p<0.01$), second ($F(1,17)=13.13$, $p<0.01$), third ($F(1,17)=6.49$, $p=0.021$), and fourth ($F(1,17)=4.60$, $p=0.046$) minute in addition to the overall session average ($F(1,17)=8.00$, $p=0.011$).

## Conclusions

The results of this study indicate that, similar to Friedland and Keinan (1992), participants who received a three-phased stress training protocol demonstrated superior performance in a stressful criterion task when compared to a control group. Participants were both more accurate and precise when asked to fly to specified headings and altitudes. Yerkes and Dodson's (1908) task dependency was also demonstrated with participants benefiting most during the more difficult maneuvering portions of the criterion session.

Stress training also was beneficial for moderating the physiological responses to stress. Furthermore, when each maneuver and straight/level portion of the criterion session was analyzed separately, the stress-trained group demonstrated lower HRV for six of the eight maneuvers, but only two of the eight straight/level portions of flight ($p<0.05$). This further indicates that stress training may be more effective for decreasing strain only for portions of a task which are inherently stressful to begin with (i.e., maneuvers). In addition, HRV and SC results were most compelling (i.e., more maneuvers found significant) for the early portions of the criterion session. This indicates an increased stress training efficacy for the onset of stress.

There was also a surprising lack of significant difference between the groups' HRV during the second TA session (control group) and the PUS session (treatment group; $p>0.05$). One possible explanation for this insignificance is the effectiveness of the stress exposure training. The stress coping strategies and exposure to the stressor gained during this session may have substantially prepared the participants physiologically for the following PUS session. Another explanation for this lack of finding is the anticipatory response of the control group. During the administrative portion of the experiment, both groups read the Informed Consent Form which stated they would be exposed to cold ice water. As the experiment progressed and the control group was still not exposed to the stressor they may have developed an anticipatory response which was equal in physiological strain to what the treatment group was experiencing under the actual cold pressor stress. Further testing of these hypotheses is needed.

The efficacy of stress training generalization to novel, real-world stressors is still largely unknown. Preliminary empirical evidence indicates the relative importance of training structure features versus domain-specific surface features (Driskell, Johnston, & Salas, 2001; Saunders, Driskell, Hall, & Salas, 1996). Furthermore, these results indicate the promise for training stress exposure in a VE as long as the structural features of the virtual training include the expected stress levels and are congruent with the real-world task(s).

Stress training is an effective means for preparing individuals for stressful flight environments. This training relies on developing the skills to accomplish a task, learning stress coping techniques, and practicing the task under stress. Although this approach is now validated within a laboratory environment, its generalization and transfer to a real-world setting requires exploration. Only when this critical connection is made can appropriate training pedagogy be developed.

References

Berntson, G., & Cacioppo, J. (2004). Heart rate variability: Stress and psychiatric conditions. In M. M. A. J. Camm (Ed.), *Dynamic Electrocardiography* (pp. 56-63). New York: Futura.

Driskell, J. E., Johnston, J. H., & Salas, E. (2001). Does stress training generalize to novel settings? *Human Factors, 43*(1), 99-110.

Friedland, N., & Keinan, G. (1992). Training effective performance in stressful situations: Three approaches and implications for combat training. *Military Psychology, 4*(3), 157-174.

Grossman, S. P. (1967). *A Textbook of Physiological Psychology*. New York, NY: Wiley and Sons, Inc.

Johnston, J. H., & Cannon-Bowers, J. A. (1996). Training for stress exposure. In J. E. Driskell & E. Salas (Eds.), *Stress and Human Performance* (pp. 223-257). Mahwah, NJ: Lawrence Erlbaum Associates.

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping*. New York: Springer.

Mackie, R., & Miller, J. (1978). *Effects of hours of service, regularity of schedules, and cargo loading on trucks and bus driver fatigue* (HFR- No. TR-1765-F). Goleta, GA: Human Factors Research, Inc.

Meichenbaum, D. (1993). Stress inoculation training: A 20-year update. In P. M. Lehrer & R. L. Woolfolk (Eds.), *Principles and Practice of Stress Management* (Second ed., pp. 373-406). New York: The Guilford Press.

Osgood, C. E. (1949). The similarity paradox in human learning: A resolution. *Psychology Review, 56*, 132-143.

Overton, D. A. (1964). State-dependent learning produced by depressant and atropine-like drugs. *Psychopharmacology, 10*(1), 6-31.

Pfieper, S. J., & Hammill, S. C. (1995). Heart rate variability: Technique and investigational applications in cardiovascular medicine. *Mayo Clinic Proceedings, 70*, 955-964.

Rosenbaum, M. (1980). Individual differences in self-control behaviors and tolerance of painful stimulation. *Journal of Abnormal Psychology, 89*, 581-590.

Saunders, T., Driskell, J. E., Hall, J., & Salas, E. (1996). *The effects of stress inoculation training on anxiety and performance*. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Selye, H. (1974). *Stress without distress*. New York: New York: American Library.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review, 8*, 247-261.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18,* 459-482.

*Acknowledgements*

The work presented in this paper is a portion of the author's PhD dissertation. The author would like to thank his dissertation advisor, Dr. Michael McCauley, and the following Naval Postgraduate School faculty members for their continued support: Drs. William Becker, Anthony Ciavarelli, Rudy Darken, Ronald Fricker, Nita Miller, and Brent Olde. Finally, the author would like to thank the Office of Naval Research and the United States Air Force Academy for their funding and support.