Coping and Changes in Arousal After Exposure to $+G_z$ Load

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BACKGROUND: Acceleration load causes several physiological changes that play important roles in pilot performance. One of the problems is determining individual factors responsible for the differences in changes in the level of central nervous system (CNS) arousal after exposure to acceleration loads. We were interested in whether the coping style and anxiety as a trait might differentiate the subjects in terms of reactions of the CNS to $+G_z$ load-related stress.

METHODS: Examined were 31 male volunteers with ages between 23 and 30 yr. Measurements were obtained under controlled conditions before, during, and every 2 min up to 12 min after centrifugation. The study was conducted using the Coping Inventory for Stressful Situations (CISS) and State Trait Anxiety Inventory. The value of Critical Flicker Fusion Threshold (CFFT) corresponded to the level of CNS arousal.

RESULTS: Two significantly different trends of changes in CNS arousal were identified: class 1 (higher level of fatigue following $+G_z$ load) and class 2 (lower level of fatigue following $+G_z$ load). Significant differences were observed in CISS scores with Task-Oriented Coping value in class 1 ($M = 65.94$, $SD = 5.47$) being considerably greater than in class 2 ($M = 62$, $SD = 4.37$). For Emotion-Oriented and Distraction Coping, the mean value in class 1 ($M = 29.53$, $SD = 7.72$; $M = 16.82$, $SD = 3.8$) was significantly lower than in class 2 ($M = 34.33$, $SD = 6.68$; $M = 19.42$, $SD = 3.4$).

DISCUSSION: The nature of the changes in CFFT values over time is associated with coping style. Coping styles are very valuable in the prediction of CNS arousal caused by exposure to $+G_z$ stress.

KEYWORDS: coping, stress, $+G_z$ load, centrifugation, arousal.

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When performing aviation-related tasks, pilots are exposed to several environmental factors that may affect the quality and style of their performance. Acceleration load is the factor of key importance. Exposure to $+G_z$ loads results in physiological changes. In general, $+G_z$ stress decreases blood pressure and blood flow velocity, which leads to hypoperfusion of the cerebral tissue, reduced cerebral oxygen saturation, and consequently G-induced loss of consciousness.[17,23] Changes occurring as a result of $+G_z$ loads are observed immediately after the exposure and vary over time. This applies to both changes in cognition and mood and changes in the levels of catecholamines or heart rate.[3,12,15]

These changes translate into central nervous system (CNS) fatigue and arousal levels, further affecting pilots' cognitive and motor performance. As a consequence, these changes are crucial for the maintenance of appropriate situational awareness during flight.[24] For example, as shown in one of the studies, exposure to gravitational loads leads to an impaired ability to recall information from visual and spatial memory and improved speed while performing cognition-related tasks. According to the authors, these effects may be related to changes in CNS arousal secondary to changing hemodynamics. In another study, impairment of verbal memory was observed following exposure to high $+G_z$ load.[12] The results demonstrated that words coded in $+1\ G_z$ were well recognized under sustained high $+G_z$ load. On the other hand, poorer recognition was observed with regard to words coded under sustained high $+G_z$ load. Therefore, it may be inferred that sustained high $+G_z$ disturbs the process of coding of verbal material rather than its retrieval.

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In our previous study, an increase in energetic arousal and decrease in tense arousal was observed after centrifugation.[3] In addition, tense arousal was reduced immediately after centrifugation, while the elevation of energetic arousal was observed up to 30 min thereafter. Changes observed in the above studies were secondary to alterations in the level of arousal of the CNS, hemodynamic variations, and associated fluctuations of hormone levels.

For the evaluation of CNS arousal changes, the Critical Flicker Fusion Threshold (CFFT) is commonly used.[6,20] CFFT is defined as the threshold at which the subject perceives the exact moment when flickering light becomes continuous and the moment when continuous light begins to flicker. Thus, CFFT is a measure of the impact of environmental stimuli, workload, and cortical arousal.[4,14] Other available studies suggest the potential of CFFT to predict higher cognitive functions.[10,13,25]

The question is whether it is possible to determine individual factors associated with psychological characteristics that might differentiate subjects in terms of CNS arousal in response to +G_z loads. In this context, attention was focused mainly on the role of coping strategies/styles and anxiety among subjects functioning under stress. For example, the study by Delahaij[7] shows that assuming a problem-oriented coping style has a positive impact on the efficacy of military training and performance in stressful situations. A reaction to strong, stressful stimuli may stem from individual traits or from acquired coping strategies. It may be illustrated by the effect of guided imagery on the reactions under gravitational load-induced stress. Guided imagery was shown to reduce emotional stress, anxiety, and sympathetic nervous system activity before and after centrifugation.[11,27]

Thus, our study ensued from the assumption that +G_z loads lead to changes in CNS arousal. We hypothesized that individual differences resulting from anxiety as a trait and coping styles would differentiate subjects in terms of CNS reactions to +G_z loads.

METHODS

Subjects

A total of 31 male pilot candidate subjects ages 23 to 30 yr took part in the study. None of the subjects had any previous experience in centrifuge testing. Following approval of the study protocol by the Ethical Committee at the Military Institute of Aviation Medicine (MIAM), each participant was thoroughly familiarized with the methodology of the study, security conditions, and the task before signing a consent form. As the next step, pilots were tested by the Central Military Aviation Medical Commission and considered able to tolerate accelerations generated in the centrifuge. The subjects were not wearing anti-G suits. They did not perform the L-1 anti-G straining maneuvers, but instead employed muscular straining of the lower limbs and abdomen. Subjects were seated in a reclined position at a 12° angle relative to the vertical axis, with arms supported at the level of the heart. The feet were supported on rudder pedals, making it possible to perform muscular strains.

Equipment

The study was conducted in a human centrifuge at the MIAM. Detailed information about this centrifuge can be found in a publication by Biernacki et al.[3]

For the CFFT examination, an FLIM Flicker/Fusion Frequency device developed by Schuhfried (Mödling, Austria) was used. Frequency of fusion of the light stimuli ranged from 25 Hz to 60 Hz. The red light stimulus had the following physical properties: diameter 1.2″, luminance $270 \text{ cd} \cdot \text{m}^{-2}$, and wavelength 665 nm.[13]

Coping strategies were assessed using the Coping Inventory for Stressful Situations (CISS) scale, which describes the strategies of coping assumed by individuals in stressful situations.[21] Coping strategies are categorized into three types: problem-focused style (PFS); emotion-focused style (EFS); and avoidance-focused style (AFS). The latter may be expressed in dual fashion: involvement in substitute activity (ISA) and search for social contacts (SSC). Anxiety level was evaluated using the State Trait Anxiety Inventory, which describes the emotional status in terms of anxiety as a state or as a trait.

Procedure

Before the centrifuge tests, subjects were assessed for level of anxiety and preferred coping strategies. The acceleration operation program is presented in **Fig. 1**. In the introduction, adaptation to centrifugation from the starting point up to a maximum of +3 G_z was carried out. In the main part of the centrifuge program, acceleration was increased linearly at a gradual onset rate (GOR) of $0.1 \text{ G} \cdot \text{s}^{-1}$ until subjects reported visual disturbances up to 28% peripheral light loss. To assess visual disturbances, as a criterion of acceleration tolerance level (ATL), the visual-motor analysis system developed at MIAM was used.[26] Maximum sustained acceleration was limited to +8.0 G_z. The condition for correct completion of the test consisted in ATL measured at the minimum level of +5.7 G_z.

During the centrifuge test, CFFT was determined nine times (nine cycles). The protocol consisted of three stages, as presented in Fig. 1.

- Prestart measurements: measurements were made in the human centrifuge cabin immediately before the start of training in the centrifuge and up to +3 G_z.
- Measurements after +3 G_z training.
- Measurements after GOR: measurements after stopping the centrifuge performed every 2 min for up to 12 min.

The examined volunteer had to identify the moment at which flickering light was perceived as constant. During each measurement time, five reactions of the CFFT test were made. Thus, CFFT was calculated as the mean value from five reactions at each measurement time. Over the course of testing, other physiological parameters not reported in this paper were routinely recorded during all centrifuge runs.

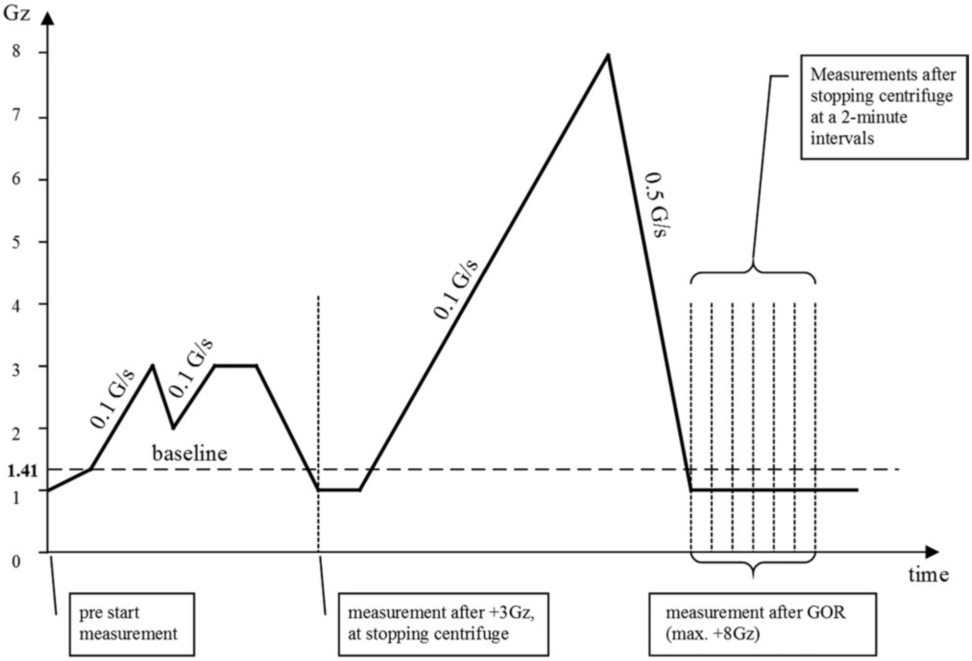

Fig. 1. Acceleration profile and sequence of CFF measurements.

Statistical Analyses

Descriptive statistics methods were used for repeated measures of CFFT and for self-report variables in the scheme in which the measurement time point was treated as the within-subject factor. Because we hypothesized about individual differences in reactions of the CNS, growth mixture model analysis was performed to differentiate groups of subjects according to the pattern of changes in their CFFT value. Then differences in the level of individual traits were evaluated within the identified groups.

All analyses were performed using statistical software R version 3.1.2;[22] growth mixture model analysis was performed using the "lcmm" 1.7.2 package;[19] and plots were created using the "ggplot2" 2.0.0 package. Power analysis was conducted with "pwr" package v. 1.1-3.[5]

RESULTS

CFFT was registered in 29 male volunteers after passing the GOR program in the centrifuge. Mean GOR tolerance ATL was +6.9 G_z (SD = 0.56). Two volunteers were excluded from the study because of low ATL values and were not included in the statistical analysis. Descriptive statistics for repeated measures and variables are presented in **Table I**. Descriptive statistics of the questionnaire results in the whole group were as follows: 30.03 (SD = 5.38) for ×2; 64.31 (SD = 5.34) for PFS; 31.52 (SD = 7.57) for EFS; and 45.1 (SD = 7.99) for AFS (M = 17.9, SD = 3.8 for ISA and M = 17.69, SD = 3.7 for SSC). Mean ATL was +6.31 G_z (SD = 0.56). All variables approximated normal distributions.

Although there are only small apparent differences in average CFFT results across all of the time points, closer inspection reveals considerable individual variability. Therefore the growth mixture modeling performed using the "lcmm" 1.7.2 package[19] was applied in order to extract homogeneous curves of changes in CFFT over the course of the study. Measurement times were included as an ordered factor and orthogonal polynominal trends were allowed to vary across possible latent classes. Model fitting procedures for the two-class mixture model resulted in a log likelihood value of −1051.73 and a Bayesian Information Criterion (BIC) of 2197.74. For class 1 (higher level of fatigue following +G_z load), the estimate for the intercept Mi = 386.91 was significant ($P < 0.001$), as was the estimate for the cubic trend: Mc = −7.76 ($P = 0.007$); in contrast, for class 2 (lower level of fatigue following +G_z load), only estimates for the intercept (Mi = 385.18, $P < 0.001$) and linear trend (Ml = −9.32, $P = 0.008$) were significant with insignificant quadratic (Mq = 4.08, $P = 0.318$) and cubic trends (Mc = 0.61, $P = 0.847$). Higher polynominal trends were not significant for both classes. Reproduced means for the two-class model are shown in **Fig. 2**.

The mean trends graphically depict similar mean levels of the intercept for both classes with a strong decrease and almost immediate improvement after centrifugation in class 1, whereas a stable linear decrease in consecutive measurements is observed in class 2. Means of posterior probabilities in each class were: 0.982 vs. 0.018 in class 1 and 0.195 vs. 0.805 in class 2. Assortment of individuals based on their most likely class resulted in the following numbers and proportions: 17

Table I. Descriptive Statistics for CFFT at Various Stages of Exposure ($N = 29$).

TYPE OF MEASUREMENT	MEAN	MINIMUM	MAXIMUM	STANDARD DEVIATION
Pre-Start	391.07	341	479	34.38
After +3.0 G_z	382.90	335	443	33.30
After GOR	382.07	305	468	39.09
Follow-up (2 min)	387.28	328	457	36.20
Follow-up (4 min)	384.55	326	457	36.52
Follow-up (6 min)	386.72	319	460	34.93
Follow-up (8 min)	387.08	317	459	36.08
Follow-up (10 min)	387.93	324	457	36.12
Follow-up (12 min)	387.10	322	468	36.38

GOR: gradual onset rate.

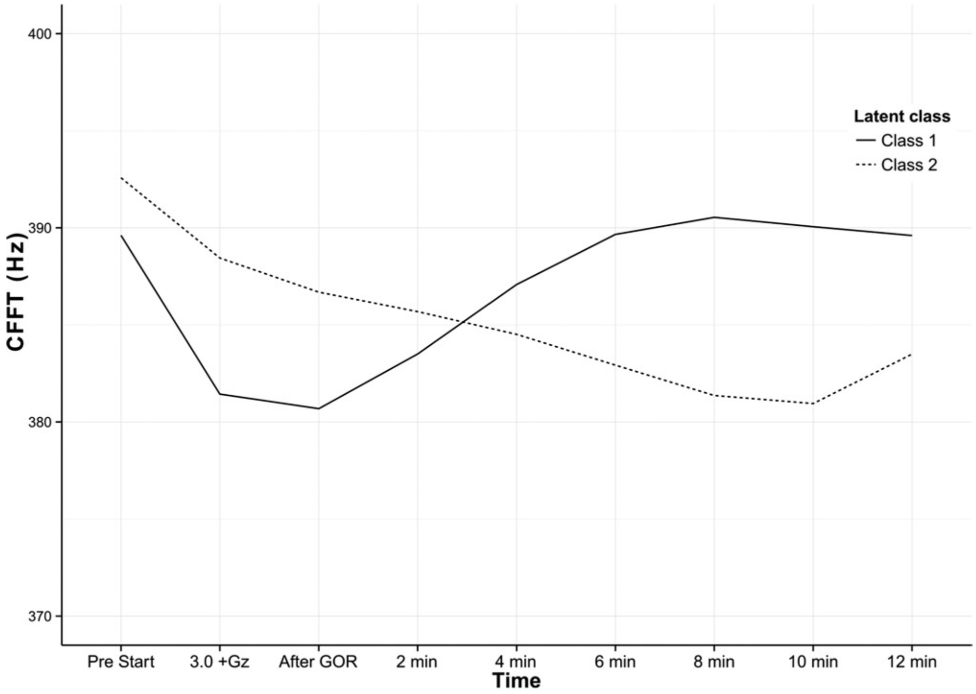

Fig. 2. Two-class mean predicted curves based on CFFT results obtained over consecutive stages of exposure.

(58.62%) for class 1 and 12 (41.38%) for class 2. Given the significant estimates derived from the two-class model, the viability of a three-class solution was examined. Model fitting procedures for the three-class mixture model resulted in a worse model fit based on BIC criterion (log likelihood value of −1045.95 and BIC of 2209.75). The third latent class appeared to be a split of class 2 from the two-class mixture model based mostly on different initial scores, so the three-class model was rejected as a model with no additional explanatory value for estimating the patterns of change. The four-class model resulted in an even worse fit (log likelihood value of −1041.05, and BIC of 2223.52), with group frequency as low as 3 in one of the classes. Eventually, the two-class model classification was accepted for further analysis.

In the next step, both classes were assessed for between-group differences. After checking for normality of distributions and homogeneity of variances, a one-sided Student's *t*-test was performed for all interindividual variables. Sensitivity power analysis (using the “pwr” 1.1-3 package) showed that with the available sample size, alpha = 0.05, and power = 0.80, the minimal detectable effect approximates Cohen's $d = 0.96$.

Analysis showed no significant differences with regard to mean ATL among two latent groups [$t(27) = -0.95$, $P = 0.17$], as well as no significant differences with regard to ×2 [$t(27) = -0.81$, $P = 0.213$]. On the other hand, significant differences were observed in CISS scores, with considerably greater PFS value in class 1 (M = 65.94, SD = 5.47) than in class 2 (M = 62, SD = 4.37) [$t(27) = 2.07$, $P = 0.024$, Cohen's $d = 0.78$]. For EFS, the mean value in class 1 was significantly lower (M = 29.53, SD = 7.72) than in class 2 (M = 34.33, SD = 6.68) [$t(27) = -1.74$, $P = 0.046$, Cohen's $d = 0.66$]. Although there were no significant differences in the overall AFS score [$t(27) = -0.31$, $P = 0.378$], analysis of the subscales showed significantly lower scores (M = 16.82, SD = 3.8) in class 1 than in class 2 (M = 19.42, SD = 3.4) for ISA [$t(27) = -1.89$, $P = 0.035$, Cohen's $d = 0.71$]. Differences in the SSC subscale were not significant [$t(27) = -0.07$, $P = 0.471$]. Graphic representation of differences in CISS scales is shown in **Fig. 3**.

Effect sizes of detected significant differences could all be classified as a medium effect. If similar effect size should be expected with the ×2 scale, it is important to note that it lies below the minimal detectable effect considering the sample size available in this study.

DISCUSSION

The results of our study indicate that differences are observed in the course of changes in CFFT levels following exposure to $+G_z$ stimulus, while the nature of changes in CFFT over time are associated with the subject's coping style. The level of fatigue secondary to centrifugation stress was lower in subjects with problem-focused coping styles. Fatigue related to sustained $+G_z$ loads was increased in individuals preferring emotion-focused and avoidance-focused styles. Coping styles have a significant value in predicting fatigue caused by the exposure to $+G_z$ stress. The results of our study suggest that the development of task- and problem-focused strategies may lead to lower fatigue levels following $+G_z$ stress. The mechanism underlying this effect may be the result of the relationship between Task-Oriented Coping strategies and energetic arousal (mobilization mechanisms).[1,2,9,18] This approach may also contribute to the faster restoration of CNS equilibrium, which may in turn translate into more effective performance and better systemic compensation abilities. Thus, the physiological and mental costs of $+G_z$ stress are lower in individuals preferring the problem-focused style. On the other hand, coping strategies involving focus on emotions or certain aspects of avoidance may increase the level of $+G_z$-induced stress as well as fatigue level. The mechanism underlying this effect may be the result of the relationship between Emotion-Oriented with emotional tension.[9] Studies by Jing et al.[11] showed that appropriate mental training may reduce the physiological costs resulting from the exposure

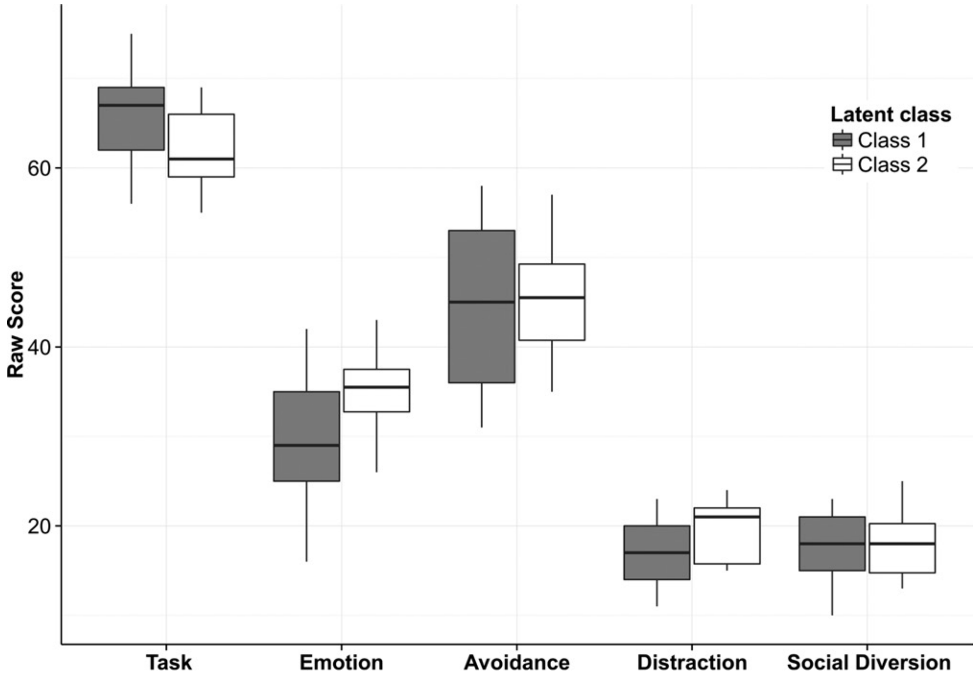

Fig. 3. Comparison of CISS scales resulted in two latent classes.

to +G_z loads. Therefore, from this perspective, appropriate mental training and effective coping strategies may reduce emotional tension and increase energetic arousal, causing effective functioning after exposure to +G_z loads. +G_z load as a significant environmental stimulus activates various coping mechanisms.[7,8] On the one hand, it may cause mobilization of extra energy through mental effort. Such a coping strategy can help in the adaptation to situational demands by decreasing fatigue and workload.[9]

+G_z load can also constitute a hazardous situation in which activation of emotional tension and stress occurs. Such a coping strategy is non-adaptive to situational demands by increasing fatigue and workload.[9] Thus, the importance of coping strategies and anxiety in the context of +G_z load is of particular importance. Research by Jing et al.[11] showed that it is possible to support coping strategies by introducing guided imagery techniques during centrifugation training. Effective coping introduced by guided imagery reduced stress and anxiety levels during centrifuge training and decreased the physiological cost of +G_z load. Thus, it is likely that training focused on the variability of coping strategies might bring about additional positive results in pilots. Understanding one's own difficulties and limitations ensuing from interindividual differences might translate into a better awareness of one's limitations and capabilities.

One of the key problems is the time within which CFFT values should be registered. CFFT examination time was based on several studies concerning physiological changes following centrifugation stress. For instance, in the study of Miyamoto et al.,[16] the level of plasma catecholamine and cortisol concentrations were assessed during the 6 min after the +G_z load. However, in another study, Mills and Marks[15] observed changes in the cortisol level 20 min after +G_z load. Thus, we decided that a period of 12 min after centrifugation load is sufficient to capture potential changes in CFFT. Of course, in future studies, it would be worthwhile to expand the time post-G_z.

The obtained results are mostly applicable in those tasks where exposure to high G load is common (high-performance military aircraft, aerobatic flying, or spacecraft). The results of the study indicate the importance of coping strategies in mediating CNS arousal changes following high environmental stress (+G_z load). In future studies, it would be worthwhile to introduce different kinds of environmental stressors (e.g., hypoxia or spatial disorientation) and expand the time post-G_z. It would also be interesting to introduce another kind of G load (e.g., the push-pull effect or rapid onset rate). Naturally, further research is required to shed more light onto those issues.

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