Neuroendocrine Responses to Psychological Workload of Instrument Flying in Student Pilots

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Background: Information processing and stress tolerance are necessary features for instrument flying (IFR), especially among student pilots. Psychological workload of IFR flight may lead to stress reactions such as neuroendocrine activity. Methods: Neuroendocrine responses to an IFR flight with Vinka piston-engined primary trainer were studied in 35 male volunteers who participated in the basic military flying course of the Finnish Air Force (FAF). The student pilots performed a 40-min IFR flight mission and a control session on land in randomized order between 11.00 h and 15.00 h. The IFR flight included 3 NDB approaches and was evaluated by flight instructors. Blood samples were collected 15 min before, 5 min and 60 min after the flight as well as control session, and. Plasma ACTH, β-endorphin (BE), cortisol, prolactin, adrenaline (A) and noradrenaline (NA) were measured. Psychological evaluations included psychomotor test (Wiener), Multi Coordination and Attention Test, ability tests and personality tests (CMPS and 16 PF). The overall psychological evaluation was made by an aviation psychologist. Results: Plasma ACTH was significantly higher before and 5 min after the flight compared with control levels, but plasma BE increased significantly only before the flight. Plasma cortisol was significantly elevated before and 5 min after the flight. Plasma prolactin, NA and A increases were significant 5 min after the flight. High A levels after the flight correlated significantly with poor IFR flight performance as well as with poor psychomotor test results. Conclusions: The plasma prolactin and NA increases after the flight represented a direct type of stress reaction to the flight situation. The plasma BE response to IFR flight was an anticipatory stress reaction, but plasma ACTH, cortisol and A responses included both anticipatory and direct types of stress reactions. Psychological factors, flight performance and neuroendocrine responses to IFR flight appear to be associated with each other. Therefore, neuroendocrine reactions as a response to the psychological workload of military flying could be used for identifying stress tolerance in military pilots.

Keywords: ACTH, beta-endorphin, cortisol, prolactin, adrenaline, noradrenaline, stress, aerospace medicine, man.

Modern fighter flying in combat situations has contributed to an increasing information load of fighter pilots (2). The psychological workload of pilots flying a high-performance aircraft (e.g., F-18 Hornet) has become a major problem in military aviation. Therefore, a better understanding of the psychophysiological stress reactions is needed to increase flight safety.

Insufficient information processing and poor stress tolerance can lead to different forms of stress reactions, such as overstimulation of neuroendocrinologically regulated hormones (31). Pituitary hormones, for example, are known to react to acute stressors. A certain level of neuroendocrine activation in response to a psychological workload evidently increases a pilot's ability to perform the flight mission (19). However, very high anticipatory levels of ACTH have been shown to correlate negatively with psychomotor performance (12). Aerobic flight in novice pilots (18), +Gz environment (1) and parachuting (22) have been found to increase plasma prolactin. However, Biselli and co-workers have documented that normal military flight stress causes increases in plasma prolactin, GH and cortisol only in young student pilots (3). We observed that prolactin responses to IFR flying were similar in cadets and experienced pilots (11). In a study with female pilots, flight-induced plasma prolactin increases did not correlate with flight experience (25).

Increased levels of circulating ACTH and β-endorphin (BE) are known to reflect the stress-induced proopiomelanocortin (POMC) gene expression in the anterior lobe of the pituitary. Plasma cortisol mirrors the peripheral efficacy of ACTH. In psychological tests, high levels of ACTH and BE are known to increase sensitivity and reduce extraversion, while high cortisol relates to the levels of activation and concentration (19). However, constantly high levels of demand generally show a rapid hormone adaptation to the stimulus (31).

Previous studies have shown that in aerospace medicine normal flight has no effect on plasma cortisol (11), but intensive military flying (25), aerobic flying (18), +Gz-stress (1), flight-induced motion sickness (4), parachuting (22) and commercial flying in emergency situations (27) do increase cortisol levels. Plane type, crew position (9) and flight experience (3,27) also have an effect on cortisol secretion, but major individual differences in the cortisol responses may occur (20).

As early as in the 1950s, the Nobel-prize laureate Ulf von Euler and his colleagues tested methods for urinary...
catecholamine in military pilots and were able to show that catecholamine secretion was related to the intensity of the flight stress (5). In later studies intensive military flying and aerial combat maneuver flight missions (6,13,21), repetitive flight missions (16), commercial and military flying in emergency situations (14,27) and parachuting (23) have been reported to enhance the secretion of sympathetic-adrenal hormones. Aircraft type, crew position and flight experience (16,27) have an effect on catecholamine secretion. In the flight simulator, repeated missions resulted in diminished catecholamine secretion, unlike in the real flights performed with high-performance aircraft (13). In general, there appears to be a significant difference in noradrenaline responses between stress-resistant and nonstress-resistant persons (10). Most of these studies concerning catecholamine and flying have been performed by using urine sampling. Because the results are expressed as secretion per minute or hour, rapid changes in the secretion of catecholamine may have been missed.

It is evident that stress hormones are secreted during flight missions but their correlations to information load and stress tolerance as well as flight performance have previously been poorly studied with modern techniques of clinical chemistry. The present study aims to evaluate neuroendocrine responses associated with stressful military flying and correlate these changes to flight performance and psychological test results. Therefore we measured plasma prolactin, ACTH, β-endorphin, cortisol and catecholamine responses in relation to the psychological workload of evaluated instrument flight in student pilots and correlated these results with psychological evaluations including personality tests (CMPS and 16PF), psychomotor tests (MCAT and Wiener) and ability tests carried out by an aviation psychologist.

METHODS

Subjects

For this study 35 male student pilots (aged 19–21 yr) of the Finnish Air Force Reserve Officer Course (ROC) were selected on a volunteer basis. All subjects had about 30 flight hours including two IFR flights with a flight instructor at the time of the study. They had passed the aeromedical examination within the past 12 mo and were healthy at the time of the study. The protocol for this study was approved by the Ethical Review Board of the Oulu Medical School. Informed consent was obtained beforehand from each subject.

Procedure

The student pilots performed a 40-min IFR flight mission and a control session in randomized order between 1100 hours and 1500 hours. The IFR flight included three NDB approaches with the Valmet Vinka piston-engined primary trainer, and flight performance was evaluated by flight instructors. During the control session subjects were in the laboratory without duties. Blood samples were collected from the vena cephalica 15 min before the flight or control session, and 5 min and 60 min after the flight or session. Blood was collected in ethylenediaminetetraacetic acid (EDTA) tubes for hormone measurements. Sample tubes were centrifuged within 30 min and stored at −20°C until analysis. ACTH, β-endorphin (BE), cortisol, prolactin, adrenaline (A) and noradrenaline (NA) were measured from plasma. Plasma prolactin was measured by two-site chemiluminescent immunoassay using the Ciba Corning ACS-180 analyzer (Medfield, MA). For ACTH and β-endorphin measurements, 2-ml plasma samples were extracted with Sep-pak C-18 cartridges using a Gilson ASPEC automatic preparation system. The Sep-pak eluates were dried in Speed-Vac, reconstituted with RIA buffer and measured in ACTH and β-endorphin radioimmunoassays. The recovery of synthetic ACTH 1–39 and human β-endorphin was 60.9 ± 3.2 and 68.0 ± 5.8%, respectively (32). Plasma cortisol was measured by radioimmunoassay (Orion Diagnostica, Espoo, Finland). Plasma adrenaline and noradrenaline were determined by high-pressure liquid chromatography (HPLC) using commercial reagents (Bio-Rad, Diagnostics Group, CA).

Psychological tests included psychomotor tests (Wieners's test and Multi Coordination and Attention Test), 21 ability tests and two personality tests (CMPS and 16PF). An aviation psychologist evaluated the subjects, awarding 1 to 5 points to each subject based on the psychological test scores and interviews of the flight instructors.

Statistics

The hormone results are expressed as means ± SEM. The data were analyzed using repeated measurements analysis of variance (ANOVA) followed by the Student-Newmann-Keuls test for the statistical significance. Correlation tests between hormone results and psychological tests were performed using the Pearson correlation model. Differences of p < 0.05 were considered statistically significant.

RESULTS

Plasma ACTH responses to the IFR flight and control period are shown in Table I. Plasma ACTH increased significantly (p < 0.01) before the IFR flight compared with the control level. Plasma ACTH level 5 min after the IFR flight was also significantly elevated compared with 60 min after the flight (p < 0.05) and the control (p < 0.05). No statistical changes of plasma ACTH were observed during the control period. Fig. 1 shows the correlation between psychological test results and plasma ACTH increases during the IFR flight.

Plasma BE responses to the IFR flight and control period are shown in Table I. Plasma β-endorphin increased significantly (p < 0.01) before the IFR flight compared with the control level. Plasma BE decreased significantly from before the flight compared with 5 min after the flight (p < 0.05). No statistical changes of plasma BE were observed during the control period. Fig. 2 shows the correlation between psychological test results and plasma BE increases during the IFR flight.

Plasma cortisol responses to the IFR flight and control period are shown in Table I. Plasma cortisol increases
TABLE I. NEUROENDOCRINE RESPONSES TO THE IFR FLIGHT AND CONTROL PERIOD (MEAN ± SEM, N = 35).

<table>
<thead>
<tr>
<th></th>
<th>15 Min Before</th>
<th>5 Min After</th>
<th>60 Min After</th>
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<tbody>
<tr>
<td>ACTH (pg · ml⁻¹)</td>
<td></td>
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<tr>
<td>IFR Flight</td>
<td>17.2 ± 1.6</td>
<td>15.0 ± 1.2</td>
<td>9.3 ± 0.7</td>
</tr>
<tr>
<td>Control</td>
<td>11.8 ± 1.0</td>
<td>10.8 ± 0.7</td>
<td>10.8 ± 0.8</td>
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<tr>
<td>Beta-endorphin (pg · ml⁻¹)</td>
<td></td>
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<tr>
<td>IFR Flight</td>
<td>34.7 ± 1.8</td>
<td>31.9 ± 1.4</td>
<td>29.6 ± 1.3</td>
</tr>
<tr>
<td>Control</td>
<td>29.3 ± 1.3</td>
<td>29.8 ± 1.2</td>
<td>29.8 ± 1.3</td>
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<tr>
<td>Cortisol (µmol · L⁻¹)</td>
<td></td>
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<tr>
<td>IFR Flight</td>
<td>0.40 ± 0.02</td>
<td>0.46 ± 0.02</td>
<td>0.30 ± 0.02</td>
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<tr>
<td>Control</td>
<td>0.31 ± 0.02</td>
<td>0.24 ± 0.02</td>
<td>0.24 ± 0.02</td>
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<tr>
<td>Prolactin (µg · L⁻¹)</td>
<td></td>
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<tr>
<td>IFR Flight</td>
<td>7.2 ± 0.5</td>
<td>9.1 ± 0.7</td>
<td>6.1 ± 0.4</td>
</tr>
<tr>
<td>Control</td>
<td>7.9 ± 0.7</td>
<td>7.2 ± 0.5</td>
<td>6.7 ± 0.4</td>
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<tr>
<td>Noradrenaline (nmol · L⁻¹)</td>
<td></td>
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<tr>
<td>IFR Flight</td>
<td>1.3 ± 0.1</td>
<td>2.1 ± 0.2</td>
<td>1.3 ± 0.1</td>
</tr>
<tr>
<td>Control</td>
<td>1.4 ± 0.1</td>
<td>1.3 ± 0.1</td>
<td>1.3 ± 0.1</td>
</tr>
<tr>
<td>Adrenaline (nmol · L⁻¹)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>IFR Flight</td>
<td>0.25 ± 0.02</td>
<td>0.31 ± 0.03</td>
<td>0.20 ± 0.02</td>
</tr>
<tr>
<td>Control</td>
<td>0.14 ± 0.02</td>
<td>0.12 ± 0.01</td>
<td>0.12 ± 0.02</td>
</tr>
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before and 5 min after the IFR flight compared with the controls were statistically significant (p < 0.01). The plasma cortisol level after the IFR flight was also significantly (p < 0.05) higher than before the flight. No statistical changes of plasma cortisol were observed during the control period. Fig. 3 shows the correlation between psychological test results and plasma cortisol increases during the IFR flight.

Plasma prolactin responses to the IFR flight and control period are shown in Table I. The plasma prolactin increase 5 min after the IFR flight was statistically significant (p < 0.01) compared with the control and the level before the flight. No statistical changes of plasma prolactin were observed during the control period. Fig. 4 shows the correlation between psychological test results and plasma prolactin increases during the IFR flight. Prolactin responses to an IFR flight correlated significantly with pro-opiomelancortin (POMC) secretion changes. The plasma prolactin change from pre-flight level to 5 min after the flight correlated with ACTH (r = 0.48, p = 0.003) and cortisol (r = 0.46, p = 0.006) changes.

Plasma noradrenaline responses to the IFR flight and control period are shown in Table I. A statistically significant (p < 0.01) increase in plasma noradrenaline was observed 5 min after the IFR flight compared with the level before the flight and the control. No statistical changes were observed during the control period in plasma noradrenaline. Fig. 5 shows the correlation between psychological test results and plasma noradrenaline increases during the IFR flight.

Plasma adrenaline responses to the IFR flight and control period are show in Table I. Plasma adrenaline was already significantly (p < 0.01) increased before the flight compared with the control and increased further (p < 0.01) 5 min after the IFR flight. Fig. 6 shows the correlation between psychological test results and plasma adrenaline increases during IFR flight. Plasma adrenaline increases correlated with poor flight performance as well as with poor psychomotor test results.
Fig. 3. Correlations (n = 35) between plasma cortisol increment during IFR flight and the psychological tests. All correlations differ significantly from r = 0. Psychological tests: 1) CMPS (ACH); 2) CMPS I; 3) CMPS (DOM); 4) 16 PF: Q3; 5) 16 PF: Q1; 6) 16 PF: F4; 7) CMPS III; 8) 16 PF: F1; 9) CMPS (SUC); 10) Errors in MCAT; and 11) CMPS (ACQ).

Fig. 4. Correlations (n = 35) between plasma prolactin increment during IFR flight and the psychological tests. All correlations differ significantly from r = 0. Psychological tests: 1) 16 PF: F4; 2) 16 PF: M; 3) CMPS (NUR); and 4) 16 PF: Q1.

DISCUSSION
The subjects performed the IFR flight with a Vinka primary trainer, and the flight was the first evaluated IFR flight of the student pilots. We estimated that the psychological workload of the test was high, possibly due to additional blood sampling and the test situation itself. Because the flight was performed with a primary trainer, the physical workload was low. The cockpits of modern combat aircraft are characterized by multiple displays providing so much information that a pilot has to select the essential information in complex flight situations. The IFR flight requires the same information processing strategies, and stress tolerance plays an important role.

ACTH as one of the pro-opiomelanocortin-derived hormones increased significantly before and immediately after the flight. The plasma ACTH increase also correlated significantly with results from the psychological tests carried out before flight training. Because only some subjects had high neuroendocrine responses to the flight, we propose that stress tolerance also has an effect on the neuroendocrine responses in instrument flight situations. On the other hand, stress tolerance is one of the main personal characteristics required of a fighter pilot. Plasma ACTH increased before the flight as an anticipatory stress reaction, but our previous results (12) suggest that high increases in plasma ACTH before a test situation do not predict good psychomotor performance. Plasma β-endorphin increases were also statistically significant before the instrument flight, confirming the plasma ACTH findings. Our β-endorphin antiserum cross-reacted with β-LPH, which has a three times longer half-life than β-endorphin. This explains the considerably less dramatic plasma β-endorphin increase as compared with the plasma ACTH increase. Previously, high plasma ACTH and β-endorphin responses to the psychomotor test were both specific, but not very sensitive to high information load (Leino, submitted).

Our plasma cortisol response before the flight was of a similar type compared with ACTH and β-endorphin responses. However, contrary to ACTH and β-endorphin changes during the flight, plasma cortisol was significantly elevated immediately after the flight when compared with plasma cortisol before the flight and during the control period. Observed direct stress responses to instrument flight were evidently due to the elevated plasma ACTH, since 10–30 min are required for exogenous ACTH to increase plasma cortisol levels. Based on our study as well as previous reports, measurements of plasma cortisol could be useful in acute flight stress situations, especially if a pilot has problems with stress tolerance.

We have earlier documented plasma prolactin responses after an IFR flight in cadets and flight instructors (11). In this study, plasma prolactin response to the IFR flight was also significant in student pilots. It should be noted that plasma prolactin increases did not have an anticipatory type role, like ACTH, β-endorphin...
and cortisol, and therefore prolactin seems to be a more suitable neuroendocrine stress parameter during acute stressful military flight situations. Furthermore, elevated plasma prolactin responses during the psychomotor test in the selection of military pilots were specific, but not sensitive to information load because of stress tolerance (Leino, submitted). It is possible that a decrease in the release of hypothalamic dopamine may mediate the increased prolactin responses since dopamine is known to have an inhibitory effect on the secretion of prolactin in man. Since no prolactin changes were observed during the control period, a diurnal drive of prolactin does not explain the phenomenon. All these findings are in line with a study of Biselli et al. (3), although they did not use controls and were therefore not able to establish the nature of the prolactin responses to the stressor. In an earlier study, different types of psychological stressors had an unclear correlation with plasma prolactin (24). It had been suggested that increases in plasma prolactin mirror passiveness in crisis situations (30), such as extreme military flying. Therefore, flying under normal circumstances has only minor effects on plasma prolactin, but some individuals may develop high responses during stressful flight phases, if they have problems with information processing and stress tolerance.

Traditionally, catecholamine measurements have been performed on urine samples. However, urine catecholamine measurements during psychologically loaded instrument flying can miss some rapid catecholamine changes. We found that the levels of plasma catecholamines increased significantly during the flight. Plasma adrenaline was already elevated before the flight but plasma noradrenaline did not show any significant pre-flight changes. Immediately after the flight, plasma noradrenaline increased and the increase was statistically significant. An elevated noradrenaline level can be ascribed to a sympathetic activation during the flight mission. An anticipatory reaction of adrenaline, as seen from the elevated plasma adrenaline before the flight, is known—to a certain level—to decrease reaction time and improve performance (6), both of which are needed in instrument flying. Iyer et al. also reported that the noradrenaline/adrenaline ratio increased significantly in student pilots who performed well in a
flight test situation (6), and our findings are in line with these findings. In our study, poor flight performance as evaluated by flight instructors correlated significantly with high plasma adrenaline responses after an IFR flight.

Catecholamine analysis has been used in aerospace medicine to identify levels of stress (15). Mefferd and his co-workers concluded that stress-monitoring should be used when selecting personnel for jobs requiring high cognitive performance under great psychological strain. However, this should be done precisely and carefully, and the test situation should be strictly controlled.

There seem to be psychological factors behind neuroendocrine responses to stressful situations. If a subject has problems in information processing and stress tolerance, he is likely to have high neuroendocrine activation after an IFR flight. According to personality tests the subjects who displayed a weaker emotional balance tended to have higher neuroendocrine responses to IFR flight. Also, high ambition to perform well (performance motivation) increased the neuroendocrine responses to a stress situation.

In summary, the psychological workload of instrument flying resulted in significant increases in plasma ACTH, β-endorphin, cortisol, prolactin and catecholamines. Out of these parameters plasma adrenaline responses were also significantly connected to flight performance. It is evident that individual stress tolerance of the pilot as well as psychological factors influence the neuroendocrine responses. Therefore, stress monitoring using neuroendocrine methods during the intercept pilot selection process could lead to better flight safety, save money in pilot training, and enhance the quality of the interceptors pilots.

ACKNOWLEDGMENTS

This work was supported by the Scientific Committee of National Defense (MATTINE), Finland, and The Finnish Medical Foundation. The authors acknowledge Captain Petri Lehtola, Ilmo Laaksonen, M.Sc., Mr. Mikko Pohjola, Major Leo Kohtajoki, and the personnel of the Air Force Academy, Kauhava, Finland, for their help and assistance during the study. We thank Ms. Tuula Lumijärvi for her skillful technical assistance during the hormone measurements.

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