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Workload and cortisol levels in helicopter combat pilots during simulated flights

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A B S T R A C T

Objective: Examine and compare the cortisol levels before and after a simulated flight related to workload in experienced helicopter combat pilots, searching for physiological levels of anxiety.
Method: 15 volunteer Spanish Army helicopter combat pilots (36.83 ± 8.04 years) were studied before and after a simulated flight (eight new tasks). Salivary cortisol was measured by DRG salivary cortisol ELISA, and we studied workload using the NASA-TLX.
Results: The differences in the mean values of cortisol level before (5.33 ± 1.55) and after the task at the flight simulator (4.47 ± 0.73) are statistically significant ($t_{14} = 3.301$; $p = .005$) with a high effect size ($d = 0.75$). Similar significant differences were also found ($t_{14} = 3.301$; $p = .005$) between the workload before (19.76 ± 10.54), and after the task (24.82 ± 10.42; medium effect size $d = -0.48$). No significant relationships were found between the cortisol levels and the workload.
Conclusions: Cortisol levels in saliva and workload are the usual in stress situations, and change inversely: workload increases at the end of the task, whereas the cortisol levels decrease after the simulated flight. The somatic anxiety decreases as the task is done. In contrast, when the pilots are faced with new and demanding tasks, even if they fly this type of helicopter in different conditions, the workload increases toward the end of the task. From an applied point of view, these findings should impact the tactical, physical and mental training of such pilots.

Carga mental y niveles de cortisol en pilotos de helicóptero de combate en vuelos simulados

Palabras clave:
Carga de trabajo
Ansiedad
Cortisol
Vuelos simulados
Helicópteros de combate
Pilotos

R E S U M E N

Objetivo: Examinar y comparar los niveles de cortisol antes y después de un vuelo simulado en relación con la carga de trabajo de pilotos de helicópteros con experiencia de combate, en busca de niveles fisiológicos de la ansiedad.
Método: Se estudió a 15 pilotos de helicópteros voluntarios del Ejército Español (36.83 ± 8.04 años) antes y después de un vuelo simulado compuesto por 8 tareas nuevas. El cortisol salival se midió por DRG Cortisol ELISA y la carga de trabajo con el NASA-TLX.
Resultados: Las diferencias entre los valores medios de nivel de cortisol antes (5.33 ± 1.55) y después de la tarea en el simulador de vuelo (4.47 ± 0.73) son estadísticamente significativas ($t_{14} = 3.301$; $p = 0.005$; elevado tamaño de efecto, $d = 0.75$), así como ($t_{14} = 3.301$; $p = 0.005$) entre la carga de trabajo antes (19.76 ± 10.54) y después de la tarea (24.82 ± 10.42; tamaño de efecto medio, $d = -0.48$). No hubo relaciones significativas entre los niveles de cortisol y la carga de trabajo.

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Conclusiones: Los niveles de cortisol en saliva y la carga de trabajo son habituales en situaciones de estrés, y cambian inversamente: la carga de trabajo aumenta al final de la tarea, mientras que los niveles de cortisol —y de ansiedad somática— disminuyen después del vuelo simulado. En cambio, frente a tareas nuevas y exigentes, la carga de trabajo aumenta al final. Estos hallazgos deberían afectar la planificación del entrenamiento táctico, físico y mental de estos pilotos.

Carga de trabalho e níveis de cortisol em pilotos de helicópteros de combate durante voos simulados

Palavras-chave:
Carga de trabalho
Ansiedade
Cortisol
Voos simulados
Helicópteros de combate
Pilotos

R E S U M O

Objetivo: Examinar e comparar os níveis de cortisol antes e depois de voo simulado em relação a carga de trabalho de experientes pilotos de helicóptero de combate, procurando por níveis fisiológicos de ansiedade.
Métodos: 15 voluntários pilotos de helicópteros de combate do exército espanhol (36.83 ± 8.04 años) foram estudados antes e depois de um voo simulado (8 novas tarefas). Cortisol salivar foi mensurado por DRG *Cortisol* salivar ELISA, e foi estudado a carga de trabalho usando o NASA-TLX.
Resultados: As diferenças nos valores médios dos níveis de cortisol antes (5.33 ± 1.55) e depois da tarefa no simulador de voo (4.47 ± 0.73) foram estatisticamente significantes ($t_{14} = 3.301$; $p = .005$) com o tamanho do efeito ($d = 0.75$). Diferenças significantes similares também foram encontradas ($t_{14} = 3.301$; $p = .005$) entre a carga de trabalho antes (19.76 ± 10.54), e depois da tarefa (24.82 ± 10.42); tamanho do efeito médio ($d = -0.48$). Nenhuma relação significativa foi encontrada entre os níveis de cortisol e a carga de trabalho.
Conclusão: Níveis de cortisol na saliva e carga de trabalho são comuns em situações de estresse, e mudam inversamente: a carga de trabalho aumenta ao final da tarefa, enquanto o nível de cortisol diminui depois do voo simulado. A ansiedade somática diminui quando a tarefa acaba. Em contraste, quando os pilotos enfrentam uma nova e exigente tarefa, mesmo que eles voem no mesmo tipo de helicóptero em diferentes situações, a carga de trabalho aumenta em direção ao final da tarefa. Para um ponto de vista aplicável, os achados devem impactar o treinamento tático, físico e mental destes pilotos.

Introduction

It has been well known that the cortisol levels are related with anxiety and anger in performance situations.[1] Globally, it has been demonstrated preferentially in athletes,[2–5] although there are other demanding performance settings.

Military combat helicopter pilots have a great physical and mental demanding tasks, forcing them to undergo high training loads and long-duration flights.[6]

Mental effort is tightly related to *cognitive workload*, and this to the amount of information and the level of processing that information demands. Or, in other words, cognitively loading tasks are those requiring managing and operating with large amounts of information in a non-automatic way as piloting an aircraft. In addition, mental workload has emotional correlations. In general, the effort associated to mental workload is hedonically negative, and increases general arousal. Indirectly, load makes tasks subjectively more difficult, and elicits more errors, which can imply more frustration and a lesser sense of self-efficiency.[7–9]

The anxiety reaction is an emotional state characterized by high activation levels of the autonomic nervous system, stress, worry that can alter attentional processes and other cognitive functions.[10] These responses depend critically on the subject's perception of a situation as challenging, potentially dangerous, or harmful.

Somatic anxiety is the direct result of increased physiological arousal, showing several bodily signs.[8]

Psychological manifestations such as fear, panic, alarm, restlessness, apprehension, obsessions, and attentional changes, or intrusive thoughts[9] make up cognitive anxiety, which in turn is split into two components: preoccupation or worry regarding the consequences associated with a poor performance and lack of attention, which prevents clear thinking during the task.[11,12]

Both types of anxiety can be modulated by their interpretation by individuals, who even may believe them to be beneficial to his performance,[13] indeed developing a sense of "excitation",[14] which does not interfere negatively with their performance.

However, it is known that the directional component of anxiety depends on various factors, such as the preceding temporal patterns of response to the anxiety, or the type of task.[15]

Considering these antecedents, the objective of this study is to examine and compare the cortisol levels before and after an helicopter simulated flight which includes a complex set of tasks, related to the perceived workload levels in experienced combat pilots, in order to determine the physiological levels of task related anxiety.

Method

Subjects

15 volunteer military helicopter combat pilots (14 men and 1 women) from the base in Almagro, Ciudad Real (Spain), with a mean age between 25 and 52 years ($M = 36.83$; $SD = 8.04$), took part in this study (see Table 1, where personal and professional data are explained). This sample means the whole population certified for to flight in the Spanish solely combat helicopter type ("Tigre"). The academic training and military rank were diverse, between the foreman and the lieutenant colonel. In order to take part in the experiment, participants were required to maintain a regular sleep–wake cycle for at least one day before the study and to

Table 1
Descriptive statistics: height, body mass (Bm), age, body fat (BF), body mass index (BMI) and flight hours in Tigre helicopter (FHTI).

Subject	Height (cm)	Bm (kg)	Age (years)	BF (%)	BMI (kg m^{-2})	FHTI
1	180.50	81.20	48	22.50	24.90	3211.50
2	180.00	86.00	36	20.70	26.40	2060.80
3	170.00	95.50	52	25.00	33.00	4562.20
4	170.50	66.00	41	19.20	22.70	4562.20
5	173.50	79.30	45	19.80	26.30	3021.00
6	173.00	71.40	37	24.30	23.90	2398.30
7	184.50	88.50	33	30.20	26.00	904.50
8	182.50	84.50	43	24.00	25.40	2673.70
9	178.00	86.80	34	30.30	27.40	1399.20
10	184.00	101.20	46	26.00	29.90	2378.80
11	179.00	82.70	33	26.80	25.80	1372.30
12	175.00	78.50	36	26.00	25.60	1533.10
13	167.00	62.50	37	18.20	22.40	1863.30
14	185.50	90.90	31	23.10	26.40	545.20
15	183.50	83.80	34	22.80	24.90	389.70
M	175.77	82.59	39.07	23.93	26.07	2191.72

abstain from stimulating beverages or any intense physical activity for the day of the experiment. Once in the simulator, none of them reported having had any stimulating beverage or exercise session, and they all reported a regular sleep the night before (6.0–8.5 h; $M = 7.6$; $SD = 0.8$). None of the participants smoked, and all of them reported normal hearing and normal or corrected-to-normal vision.

The experiment reported in this paper was conducted according to the ethical requirements of the local committee and complied with the ethical standards laid down in the 1964 Declaration of Helsinki. Before the beginning of the experimental session the participants read and signed an informed consent statement. They were informed about their right to leave the experiment at any time. All participants' data were analyzed and reported anonymously.

The Ethics Committee in Human Research of the University of Granada, issued a favorable report for the study.

Experimental procedures

Salivary cortisol and subjective workload were measured to pilots before and after performing a simulated flight with eight different tasks. The first and the last ones consisted of traffic and recognition flight of the work area, around the military base, and a return flight respectively, so the difficulty level must be considered medium. During the other six tasks pilots were demanded to solve different special problems according to their current training program, representing diverse cognitive and psychomotor complexity. Tasks order was randomized among pilots.

Neither before nor during the flight in the simulator, pilots were informed nor about the task to be performed nor they obtained feedback about the best maneuvers to solve them, in order to increase the workload by means of a higher cognitive uncertainty.

Each flight task started with take off and finished with landing. After that, the instructor gave the pilots general instructions for the next task, without any feedback about the past flight.

The duration mean of the eight flight tasks were 9 min 4 s, 5 min 3 s, 5 min 23 s, 5 min 8 s, 5 min 31 s, 4 min 16 s, 4 min 10 s, and 9 min 9 s, respectively.

In order to make the cortisol analysis, pilots were required to avoid eating, drinking, chewing gums or brushing teeth for 30 min before sampling. Saliva samples were collected at the beginning of each session (without stimulation, by spitting directly into a plastic tube), and immediately following completion of the last task of the simulated flight. Samples were obtained for all the subjects who participated in the study. Salivary cortisol has been shown to have a circadian rhythm.[13] To avoid any confounding effects due to variations in circadian rhythm all testing sessions were performed at the same time of day between 8 a.m. and 11 a.m. Samples were stored at −20 °C until analyzed. Salivary cortisol levels were determined by using commercial enzyme-linked immunosorbent assay (ELISA) kits (salivary cortisol ELISA, SLV-2930, DRG Instruments GmbH, Germany) with a sensitivity of 1.482 nmol/l, intra-assay variation of 1.80% ($M = 35.29 \pm 0.63$ nmol/l) and interassay variation of 7.47% ($M = 67.02 \pm 4.99$ nmol/l). The range of the assay is between 0 and 220.72 nmol/l.

In order to measure mental workload the NASA-TLX[16,17] questionnaire was used. Participants received the necessary instructions to complete it before the beginning of the first simulated flight task in a close room and isolated from external noise.

The NASA-TLX provides an overall workload score (from 0 to 100 points) based on a weighted average of ratings on six dimensions: mental demands, physical demands, temporal demands, own performance, effort, and frustration.

Participants were instructed to rate each dimension on a visual analogical scale (from 0 to 100 points). NASA-TLX obtained a reliability alpha index of 0.917.

Statistical analysis

After analyzing the nature of the data, Student's *t* test for paired samples was used, with a significance level of $p < 0.05$. To calculate the effect size, Cohen's *d* was used. The Pearson correlation coefficient was used to analyze the relationship between the two continuous variables. In order to do that, the SPSS v.21 (SPSS Inc., Chicago, IL) statistical program was used.

Results

Table 2 shows the values of cortisol and NASA-TLX, measured before and after the test in the simulator, for each one of the helicopters pilots, with average and SD values added.

There are statistically significant differences ($t_{14} = 3.301$; $p = 0.005$) between the mean values obtained of cortisol levels before the task at the flight simulator (5.33 ± 1.55), compared with those obtained at the end of the test (4.47 ± 0.73), with a high value of effect size ($d = 0.75$).

Statistically significant differences were also found ($t_{14} = -3.374$; $p = 0.005$) between the mean values of workload obtained with the NASA-TLX before the task at the simulator (19.76 ± 10.54), compared to those obtained at the end of the task (24.82 ± 10.42). These differences showed a medium value of effect size ($d = -0.48$).

No statistically significant relationships ($r = -0.151$) were found when the correlation between the differences (before and after) of cortisol levels and workload was analyzed.

Discussion

First, the raw results of the salivary cortisol are at the average obtained in similar tasks[1] in both conditions, before and after the task, including the expected individual differences among the pilots.

The significant decrease (-0.92 ± 1.07; 17.39%; $d = 0.75$) of the salivary cortisol level indicates that the activation of the pilots' autonomic nervous system (ANS) descended as the task was being completed in the simulator, so the somatic component of anxiety associated to the performance was also lower at the end, when compared to the pre-task level. Indeed, it is not possible to state if this emotional feature acts as a facilitator to the correct completion of the task.[14,18]

Table 2
Cortisol and NASA-TLX descriptive values before and after the flight simulator tasks.

Subject	Cortisol**			NASA-TLX		
	Pre	Post	Change	Pre	Post	Change
1	4.03	3.75	−0.28	18.30	13.30	−5.00
2	4.84	4.38	−0.46	10.80	22.50	11.70
3	4.82	4.20	−0.62	30.80	28.30	−2.50
4	5.33	3.39	−1.94	22.50	40.80	18.30
5	8.86	5.10	−3.76	20.80	21.70	0.90
6	4.69	4.43	−0.26	10.80	13.30	2.50
7	5.54	5.06	−0.48	10.80	17.50	6.70
8	7.43	5.31	−2.12	7.50	14.20	6.70
9	5.50	4.96	−0.54	17.50	25.80	8.30
10	8.16	6.24	−1.92	43.30	46.70	3.40
11	4.72	4.09	−0.63	15.80	20.80	5.00
12	3.79	4.15	0.36	36.70	35.80	−0.90
13	3.76	3.90	0.14	13.30	18.30	5.00
14	5.06	4.25	−0.81	10.80	18.30	7.50
15	4.31	3.90	−0.41	26.70	35.00	8.30
M ± *SD*	5.39 ± 1.55	4.47 ± 0.73*	−0.92 ± 1.07	19.76 ± 10.54	24.82 ±1 0.42*	5.06 ± 5.81

* Significative at $p = 0.005$.
** Cortisol values in nanomol/l.

Results show that the perceived mental workload increases at the end of the task performed in the flight simulator, which were designed as a new task for the pilots. This finding indicates that the effect of habituation[7] it does not occur in this case, but the uncertainty of the new cognitive tasks, the lack of continuous feedback, their perception of physical load and/or the associated fatigue while still not being in the recovery phase, have an incremental effect on the pilot's workload.[6]

While some studies have found a relationship between the perceived workload and the cortisol level among other similar physiological measures of the ANS activation,[19–21] in this study these two variables are disconnected. In addition, changes that occur in them are in reverse, as long as the perceived mental load increases, the level of cortisol in saliva decreases at the end of the task.

Therefore, it is possible to infer the level of workload via the somatic components of anxiety, such as the level of salivary cortisol.

Somewhat surprising, this amount of perceived workload has not been found in other fields of human performance such as elite sport.[22] However, it should be analyzed carefully to determine the composition and weight of the different dissociative and associative components that appear both during the task and in the recovery period.[7]

Also, after these results, we realize the need for to have an objective system for monitoring the perceived mental workload by pilots – before, during and after a task – more accurate and reliable than the behavioral observation of "nervousness" (mainly based on the apparent changes associated with the activation of ANS) which can lead to an incorrect interpretation of the mental effect of the task on the pilots.

As a general conclusion, we can say that while pilots perceived an increasing physical and mental workload as they are working in the simulator, the anxiety associated with the task decreases. Therefore, they can be seen as unrelated events, opposed to the common belief about the impact of the performance anxiety on cognitively complex tasks combined with physical load.

These results should have an impact on the design of the pilots' physical, tactical and mental training as well on the pre-flight anxiety detection systems.

This study has limitations regarding to the small number of participants (they are the only certified pilots in this helicopter model in Spain), and the use of simulated flights, due to the impossibility of study out in real flights.

Due in part to these limitations, future studies have to determine if the cognitive anxiety is due to the worries or concerns associated with the task, or if it is a source for some lack of focus, since the anxiety mode has a direct impact on the pilots' performance when it is objectively assessed. Also, the pilot's perception of fatigue and recovery after the accomplishment of the task should be analyzed in terms of its relationship with the global workload.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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