Determining the psychophysiological responses of military aircrew when exposed to acute disorientation stimuli

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ABSTRACT

Introduction Exposure to environmental flight conditions may impair performance and physical integrity, thus training in simulated environments it is a key factor. This research aimed to study the psychophysiological response, cortical arousal and autonomic modulation of pilots and medical aircrew personnel during disorientation exposure, considering gender, experience, flying hours and body mass index (BMI) as influential variables.

Methods A total of 47 soldiers (37 men and 10 women, 22 medical aircrew personnel and 25 fighter pilots) of Spanish Air Forces faced 25 min of vestibular, proprioceptive and visual disorientation.

Results Disorientation exposure elicited an increased psychophysiological response, significant increases in isometric hand strength, cortical arousal, autonomic modulation, perceived stress and effort in both groups while a significant decrease in respiratory muscle capacity and blood oxygen saturation in the medical aircrew group were found. Cross-sectional analysis showed gender differences, males presented greater parasympathetic activity and strength. Larger BMI was associated with greater levels and perception of stress as well as lower cardiovascular performance and sympathetic modulation. Furthermore, experience, previous training and larger flying hours correlated with greater parasympathetic modulation.

Conclusion Disorientation exposure produces an increase in cortical arousal and decrease in the parasympathetic nervous system either in pilots and medical aircrew personnel. In addition, medical aircrew personnel are less adapted to disorientation stimulus presenting significantly higher psychophysiological stress response, thus complementary physical training should be mandatory.

INTRODUCTION

Pilots and aircrew are exposed to a large number of stressors stimuli, either environmental or related to the psychophysiological demands of the flight context.1 Exposure to environmental elements, such as noisiness, vibrations, physical and psychological fatigue, and spatial disorientation may adversely affect performance and physical integrity.2 In addition, hypoxia and greater G-Forces due to the improvements in aircrafts ergonomics increase flights’ height and speed, intensifying crew’s psychophysiological response as well as their visual and auditory reaction times. In turn, these factors alter cognitive functions related to information processing, resulting in short-term memory loss and inability to maintain attentional focus, concentration difficulties, and a decrease in performance and defective.3

The exposure to the aforementioned conditions may lead to spatial disorientation, which has been linked to fatal performance mishaps with a fatality rate of almost 100%.4 In addition, it is defined as a multisensory state including vision and a complex set of psychophysiological responses, although it is important to note that in the aerospace environment, vision accounts for nearly 80% of importance.5 Therefore, to fully understand pilots and aircrew experiences and to design proper countermeasures, it is critical to build theoretical models taking into account the complex interaction between vision, proprioception and vestibular symptoms.

Taking all this into account, we believe that to fully understand spatial disorientation, it will be useful to study pilots and aircrew’s fatigue of the central nervous system (CNS; critical flicker fusion threshold, CFFT) and their autonomic modulation. CFFT has been related to attention, awareness, memory, cognitive processes and information processing as well as the experience of spatial disorientation during flight time,2 and can be objectively measured using CFFT. As for autonomic modulation, it has been shown that soldiers experiencing a stressful environment and a cognitive demanding context experience an activation of the phylogenetic fly-fight defence system, eliciting a large cholinergic and adrenergic response, which has a direct effect on soldier psychophysiological response.6

Since mental awareness and preparedness, together with autonomic modulation and cortical arousal,9 are directly linked to the operative...
response in pilots and soldiers, we propose this research with the following aim: To study the psychophysiological response, cortical arousal and autonomic modulation of pilots and medical aircrew personnel during disorientaiton exposure, considering the influence of gender, experience, flying hours and body mass index (BMI), on the psychophysiological stress response. We hypothesise that disorientation exposure would increase psychophysiological response, increasing cortical arousal and sympathetic nervous system activation, being greater on medical aircrew personnel than pilots.

**METHODS**

**Participants**

We analysed 47 soldiers (37 men and 10 women) were randomly assigned with the following characteristics: males: (35±10.2 age; 175.7±6.9 height; 74.4±10.7 kg; 13.5±9.1 years of military experience; 7.1±12.2 months of international missions; 752.6±112.7 flight hours), females (41±9.1 age; 171.1±2.1 height; 68.3±13.1 kg; 15.8±9.8 years of military experience; 18.1±2.1 months of international missions; 146.2±315.1 flight hours). From those 47 soldiers, 22 were aircrew personnel, nurses and medical doctors and 25 fighter and helicopter pilots, with the following characteristics: Medical aircrew personnel, nurses and medical doctors: (40±9.1 age; 171.1±6.7 height; 68.1±11.1 kg; 15.1±9.1 years of military experience; 17.8±3.1 months of international missions; 92.8±42.1 flight hours), and fighter and helicopter pilots: (32.6±9.6 age; 177.3±6.4 height; 77.2±9.1 kg; 12.9±9.1 years of military experience; 4.2±2.1 months of international missions; 1135.2±102.3 flight hours). All of them belonged to the Spanish Air Forces with a qualification of ‘fit’ according to the periodic medical examination as recorded in the ministerial order 23/2011. The present research was carried out during the STANAG 3114 ‘Aeromedical Training of Flight Personnel’ from the North Atlantic Treaty Organization (NATO), approved by the ministerial order 23/2011 of the Ministry of Defence of Spain. Before starting the research, the experimental procedures were explained to all the participants, who gave their voluntary written informed consent in accordance with the Declaration of Helsinki. The procedures conducted in the present research were designed and approved by the Medical Service of the Aerospace Medicine Instruction Centre of Spanish Air Forces. All simulation was performed equipped with the standard uniform, boots, equipment and flying operative helmet and mask.

**Procedure**

We analysed the psychophysiological response of soldiers, pilots and medical aircrew personnel in a disorientation exposure training during 25 min in which both groups faced vestibular, proprioceptive and visual disorientation. The exposure was supervised by the Medical Service and the ‘Training Flight Instructor of the Aerospace Medicine Instruction Centre of Spain. End of the training may occur if either the Medical Service or the Soldier noticed any medical possible risk.

**Instrumentation and study variables**

Before and after the disorientation exposure, the following parameters were analysed:

- Bodyweight was measured using a SECA scale model 714 with a precision of 100 grams (range: 0.1–130kg), located on a flat and smooth surface and calibrated at zero.
- Height was measured with a height rod incorporated in the scale Seca model 714 with a precision of 0.1 mm (range: 60–200 cm).
- Isometric hand-grip strength using a TKK 5402 dynamometer (Takei Scientific Instruments Co. Ltd).
- Subjective perceived stress (SPE) was assessed using a 0–100 scale.
- Rating of perceived exertion (RPE), 6–20 scale.
- Blood oxygen saturation was evaluated using an oximeter OXYM4000 (Quirumed, Madrid).
- Spirometry values of forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1) and peak expiratory flow (PEF) were measured using a QM-SP100 (Quirumed, Spain) spirometer, performing a maximum inhale-exhale-inhale cycle.
- Memory test: A randomised number of three digits was presented for 1 s, after 5 s, subjects had to inversely write it down, as in previous researches.
- Cortical arousal was measured through the CFFT. Increases would show CNS fatigue and a reduction in the efficiency of information processing systems.
- Heart rate (HR) and heart rate variability (HRV) by a Polar V800 HR monitor (Kempele, Finland) with a sampling frequency of 1000 Hz, with which the RR intervals can be analysed for the analysis of the HRV and the number of beats per minute for the HR analysis. Time-domain (non-spectral), frequency-domain (spectral measures) and non-linear measures were analysed.

**Statistical analysis**

The SPSS statistical package (V21.0; SPSS, Chicago, IL,USA) was used to analyse the data. Normality and homoscedasticity assumptions were checked with a Shapiro–Wilks test. Differences between pre-sample and post-sample were analysed using a Wilcoxon test for non-parametric variables and Student’s t-test for parametric variables. Spearman test was used to analyse the correlation between variables. The effect size (ES) was tested by Cohen’s D [ES = (Post-test mean − Pre-test mean)/Pre-test SD]. Differences between groups were analysed using Mann–Whitney test for non-parametric variables and Student’s t-test for parametric variables. The level of significance for all the comparisons was set at p≤0.05.

**RESULTS**

In Table 1 are shown the pre–post results, inter and intra-group comparison of the physiological and psychological variables studied in both groups, pilots and medical care aircrew in two moments, before and immediately after the finalisation of the disorientation training. Significant increases were found in HS, CFFT and perceived subjective stress (PSS) in Pilots and HS, FVC, FEV1, PEF, blood oxygen saturation (BOS), CFFT, RPE and PSS in Medical Care Air Crew as a consequence of disorientation training. When analysing differences between groups, Medical Care Air Crew presented greater pre-FVC and post-FVC and PSS values and lower BOS and CFFT values than pilots. Pilots presented greater pre-HS and post-HS and pre-CFFT values than Medical Care Air Crew.

In Table 2 are shown the results from the autonomic modulation analysis. Medical personnel aircrew presented a significant increase in HRmean, HRmax and LF, and a significant decrease in root mean square of the successive differences (RMSSD), pN50, SD1 and SD2 in the disorientation training, also showing significantly higher HRmean, RMMSD, LF, SD1 and SD2 baseline values than pilots.

When comparing differences between males and females, significant differences were found in pre-HS (males 44±10.6 vs
When comparing differences according to the BMI, being normoweight (NW=<25 BMI) and overweight (OW=>25 BMI), significant differences were found in Pre- PSS (males 66.8±23.4 vs females 56.3±13.8 p=0.030).

When comparing differences according to the soldier's experience, the cutting point was settled in 10 years of military experience following previous studies that delimited elite form (high experience) and LE (low experience, the cutting point was settled in 10 years of military experience) non- elite soldiers.

Finally, when comparing differences according to flying hours, cutting point settled in 300 hours, which is the minimum of hours required by a pilot to fly autonomously, high flying hours (HFH) and low flying hours (LFH). The present variables presented significant differences: post-disorientation training LF (HFH 63.3±16.1 vs LFH 76.9±14.1; p=0.007); post-disorientation training HF (HFH 36.5±16.9 vs LFH 23.1±15.1; p=0.006); post-disorientation training LF/HF (HFH 3.4±1.7 vs LFH 4.2±2.4; p=0.024).

**DISCUSSION**

Stress exposure induces respiratory reactions that lead to changes in ventilation, followed by changes in metabolic processes which may vary depending on the subject's intrinsically psychometric characteristics, previous experience and training in the specific context/task. In this research, we found that medical aircrew personnel presented significantly higher stress perception than pilots, as well as significantly higher fatigue of the respiratory muscles (as decreased FVC showed), in addition to a significant decrease in blood oxygen saturation, which could be related to a hyperventilation response causing hypocapnia. On the contrary, pilots, who are regularly exposed to greater stressful conditions due to their duties did not perceive the disorientation training as a potential stressful stimulus, showing no significant increases either on the RPE and SEP scale. Thus, it is also possible that the greater experience of pilots in respiratory control may have allowed them to maintain their blood oxygen saturation stable during the disorientation training, unlike the medical personnel aircrew, who lacked experience in this context.

The significant increase in isometric hand strength reported in both groups, both pilots and medical personnel aircrew, was in line with the activation of the flight-fight defense system previously reported in combat simulations where the acute sympathetic, cholinergic and adrenergic responses lead to increases in strength manifestations. This fact is also supported by the HRV analysis which, according to frequency, time-domain and non-linear analysis values evaluated, suggests autonomic modulation, with decreased vagal tone and increased sympathetic activation in both groups as a result of disorientation exposure. In addition, the increased cortical arousal identified has been linked to improvements in muscle contraction capabilities, thus increasing muscle strength. These findings are in line with our data, since CFFT values showed a significant decrease in both groups, meaning increased cortical activation, consequent with the hand strength increases and previous studies. The increase in cortical arousal is explained due to the intrinsic demands of disorientation training, which elicits large cognitive resources, producing no negative effects (CNS fatigue).

**Table 1** Results of psychophysiological variables

|                     | Pilots                      | Medical care air crew                  |
|---------------------|-----------------------------|---------------------------------------|
|                     | Pre                          | Post                                | 95% CI of the differences | Pre                          | Post                                | 95% CI of the differences |
|                      | 51.1±3.7                    | 49.1±5.6                             | (0.001)                    | 37.2±3.1                    | 35.7±4.3                             | (0.006)                    |
|                      | 0.000                        | 0.000                                | 0.36                       | 0.003                       | 0.004                                | 0.35                       |
|                      | 5.3±0.2                     | 5.0±0.6                              | (0.019)                    | 4.0±0.6                     | 4.0±0.6                              | (0.006)                    |
|                      | 0.010                       | 0.018                                | 0.18                       | 0.018                       | 0.018                                | 0.007                      |
|                      | 3.6±0.8                     | 3.0±0.6                              | (0.015)                    | 4.9±0.6                     | 4.9±0.6                              | (0.006)                    |
|                      | 0.005                       | 0.13                                 | 0.081                      | 0.13                        | 0.081                                | 0.018                      |
|                      | 9.1±2.8                     | 9.2±1.1                              | (0.015)                    | 10.3±2.6                    | 10.1±2.2                             | (0.021)                    |
|                      | 0.010                       | 0.04                                 | 0.755                      | 0.04                        | 0.755                                | 0.015                      |
|                      | 97.6±1.2                    | 96.7±1.6                             | (0.000)                    | 97.3±0.8                    | 93.1±1.2                             | (0.021)                    |
|                      | 0.009                       | 0.08                                 | 2.018                      | 0.08                        | 2.018                                | 0.015                      |
|                      | 39.3±3.2                    | 37.2±2.1                             | (0.015)                    | 37.3±4.7                    | 36.8±4.1                             | (0.049)                    |
|                      | 0.011                       | 0.11                                 | 2.174                      | 0.11                        | 2.174                                | 0.053                      |
|                      | 7.1±1.6                     | 10.7±3.1                             | (0.015)                    | 9.6±2.3                     | 9.2±1.1                              | (0.004)                    |
|                      | 0.012                       | 1.04                                 | 3.124                      | 1.04                        | 3.124                                | 0.045                      |
|                      | 19.2±21.1                   | 39.8±2.1                             | (0.015)                    | 23.8±12.6                   | 65±10.2                              | (0.000)                    |
|                      | 0.000                       | 3.27                                 | −19.934                    | 3.27                        | −19.934                               | 1.235                      |

Between parenthesis. *(p<0.05) significant values between Pilots and Medical Care Air Crew.

FOS, blood oxygen saturation; CFFT, critical flicker fusion threshold; FEV1, forced expiratory volume in 1 s; FVC, forced vital capacity; HS, hand strength; PEF, peak expiratory flow; PSS, perceived subjective stress; RPE, rated perceived exertion.
in the acute disorientation exposure analysed in the present work, in line with other studies in military population.\textsuperscript{19} Finally, the significant larger CFFT values that pilots presented, as well as the lower decrease after disorientation training, may be related to the fact that pilots have internalised and automated the technical and operative procedures, needing less cognitive resources to perform them and making them greatly operative against this stimulus.\textsuperscript{21, 22} Continuous exposure to disorientation in their daily flying training allows them to improve cognitive resources, producing a greater adaptive and operative response. Regarding the cross-sectional statistical analysis, gender differences showed how males were stronger, presenting higher significant pre-isometric and post-isometric hand strength values, possibly explained due to the higher muscle mass of males compared with females.\textsuperscript{20} In addition, males presented significantly higher parasympathetic modulation, according to higher pre-pNN50 and post-pNN50 and SD2 values. This fact could be explained by higher physical fitness of male participants, probably related with the physical tests requirements between males and females (largely more demanding for males), which forces male pilots to a much more demanding training and preparation.\textsuperscript{21, 22} This could lead to the fact that female pilots train less and therefore develop a lower psychophysiological adaptation to the task. According to the BMI, we found that overweight subjects (BMI > 25) present larger baseline levels of stress and greater stress perception according to the significant PSS pre–post- scale values, which is consequent with the actual models that describe overweight as an organic stressor. There is a vicious circle whereby greater levels of cortisol as a cytokine and inflammatory pathways that directly increase body weight and especially abdominal adiposity.\textsuperscript{23} Our data related to larger BMI with overweight subjects (BMI > 25) present larger baseline levels of stress and greater stress perception according to the significant PSS pre–post- scale values, which is consequent with the actual models that describe overweight as an organic stressor. There is a vicious circle whereby greater levels of cortisol as a cytokine and inflammatory pathways that directly increase body weight and especially abdominal adiposity.\textsuperscript{23}

### Table 2 Results of the HRV analysis

|                | Pilots | Medical care air crew |
|----------------|--------|-----------------------|
|                | Basal (R) | Disorientation training (DT) | Post-disorientation training (PDT) | Post hoc | Basal (R) | Disorientation training (DT) | Post-disorientation training (PDT) | Post hoc |
|                |          | Basal (R) |          |          |          |          |          |          |          |
| HR mean        | 78.6±14.2 | 74.8±12.1 | 78.9±14.1 | B>DT (.000) | PDT>DT (.007) | 80.7±7.9 | 89.9±7.9 | 87.1±4.9 | PDT>DT (.001) | PDT>B (.003) |
| HR Max         | 102.4±13.1 | 100.7±16.3 | 101.5±16.8 | – | 100.3±11.4 | 125.4±18.2 | 109±17.2 | DT>B (.000) | DT>PDT (.000) |
| HR Min         | 64.1±13.3 | 58.9±8.5 | 63.8±13.3 | PDT>DT (.007) | PDT<B (.006) | 63.5±6.67 | 65.6±9.1 | 72.3±1.4 | PDT>DT (.003) | PDT>B (.006) |
| RMSSD          | 39.8±22.6 | 39.5±21.2 | 45.1±20.2 | – | 42.49±19.2 | 29.21±14.1 | 32.15±12.5 | B>DT (.001) | PDT>B (.041) |
| PNN50          | 14.7±13.1 | 14.7±12.1 | 17.8±14.7 | PDT-B (.043) | 13.6±7.7 | 10.6±8.7 | 10.4±9.9 | – | – |
| LF             | 63.5±13.2 | 76.7±12.1 | 72.3±14.6 | DT>B (.013) | PDT-B (.016) | 72.3±11.3 | 89.9±1.9 | 64.9±19.6 | B>DT (.000) | PDT=B (.041) | PDT=DT (.026) |
| HF             | 26.2±13.1 | 23.1±12.2 | 27.7±14.2 | – | 27.4±11.2 | 26.6±8.8 | 34.9±19.6 | PDT>B (.012) |
| LF/HF ratio    | 3.6±2.1 | 4.2±2.3 | 5.1±2.1 | – | 3.3±2.1 | 3.1±1.5 | 3.1±2.9 | – | – |
| SD1            | 29.1±15.9 | 28.1±15.1 | 30.1±13.4 | – | 36.1±13.8 | 25.2±12.1 | 22.9±8.8 | PDT=B (.041) |
| SD2            | 92.1±18.4 | 60.2±16.9 | 72.6±24.3 | PDT>DT (.007) | PDT<B (.023) | 65.9±18.4 | 51.5±10.2 | 55.4±15.4 | B>PDT (.002) | PDT>B (.032) |

Between parentheses intergroup significant differences.

SD1: Poincaré plot standard deviation perpendicular the line of identity, SD2: Poincaré plot standard deviation among the line of identity.

* *\textsuperscript{p}<0.05; rt rate. RMSSD: Square root of the mean of the sum of the squared differences between adjacent normal R–R intervals. pNN50: the percentage of differences between R–R intervals higher than 50 ms.

HF: high frequency; HR: heart rate; LF: low frequency; n.u: normalised unit; RMSSD: root mean square of the successive differences.
as an adaptive response to the environment previously shown in previous studies in other demanding contexts and populations as elite soldiers or experienced paratroopers. This result was in line with flying hours, as lower experienced pilots presented greater sympathetic activation during training according to their higher LF and HF/LF values compared with highly experienced ones.

CONCLUSIONS
Acute exposure to disorientation training produced an increased psychophysiological response, increasing cortical arousal and sympathetic nervous system of both pilots and aircrew members being highly experienced male subjects with a greater number of flying hours and lower BMI those with lower sympathetic modulation and higher cortical arousal. Therefore, we recommend to take this knowledge into account to review and reshape current physical training programs of both pilots and aircrew members, placing a special focus on inverse perio-

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