Original Article / *Artigo Original*

Effects of Workload in Novice Military Transport Flights on Autonomic Modulation and Cognitive Performance: An Observational Cross-Sectional Study

Efeitos da carga de trabalho na modulação autônoma e no desempenho cognitivo durante voos de transporte militar em pilotos novatos: um estudo observacional seccional

Mendes et al.

Enyo Mendes, Grace Barros Sá, Renato Massaferri, Iransé O.-Silva, Walace Monteiro, Paulo Farinatti
Revista de Educação Física / Journal of Physical Education (2021) 90, 4, 282-298

Revista de Educação Física
Journal of Physical Education
Home page: www.revistadeeducacaofisica.com

Original Article

Artigo Original

Effects of Workload in Novice Military Transport Flights on Autonomic Modulation and Cognitive Performance: An Observational Cross-Sectional Study

Efeitos da carga de trabalho na modulação autônoma e no desempenho cognitivo durante voos de transporte militar em pilotos novatos: um estudo observacional seccional

Enyo Mendes [1] MSc, Grace Barros Sá[2] MSc, Renato Massaferri[3] PhD, Iransé Oliveira-Silva[4] PhD, Walace Monteiro[1,5] PhD, Paulo Farinatti[§1,5] PhD

Received: September 28, 2021. Accepted: November 25, 2021.
Published online: December 20, 2021.
DOI:

Abstract

Introduction: Flight-related stress influences pilots' health and performance. Research investigating the influence of workload during military flights on those outcomes is warranted.

Objective: This study investigated the effects of perceived workload during military transport flights on autonomic modulation and cognitive performance in novice Brazilian Air Force pilots.

Methods: In this cross-sectional observational study, 15 pilots (25±1 years; 222±37 h flight-time; 47.6±3.9 ml.Kg-1.min-1) underwent two successive flights (50-75 min), as pilots (P1) and copilots (P2). Perceived workload was assessed using the NASA-TLX inventory. Autonomic modulation during the flights was evaluated by heart rate variability. Cognitive performance pre- *vs*. post-flights was compared using the Stroop color-word test.

Results: The perceived workload during flights was moderate (~5 points), with a 5-fold greater contribution of 'mental' *vs*. 'physical demand'. Flights provoked a 2-3 fold increasing in sympathetic modulation, with 50% greater average autonomic changes in P1 than P2 (Δ max/min; p<0.05): RRi (P1: Δ -189/-199 ms; P2: Δ -164/-177 ms), RMMSD (P1: Δ -24/-25 ms; P2: Δ -16/-18 ms), pNN50 (P1: Δ -19/-20%; P2: Δ -15/-20%), LF (P1: Δ 19/24 u.n.; P2: Δ 19 u.n.), HF (P1: Δ -19/-23 u.n.; Δ P2: -18/-19 u.n.), LF/HF (P1: Δ 4/5; P2: Δ 3/4). Correlations between NASA-TLX and sympathetic modulation were inverse *vs*. 'physical demand' and 'overall workload' (r_s= -0.52/-0.63), and direct *vs*. 'mental demand' (r_s =0.57), the opposite occurring for parasympathetic modulation (r_s =0.47/0.59; r_s = -0.45/-0.47; p<0.05). The cognitive performance was unaltered and uncorrelated with NASA-TLX components.

> ***Key points***
> *- Military transport flights increased sympathetic and decreased vagal modulation in novice pilots.*
> *- Perceived workload correlated with autonomic changes, but not with cognitive performance.*
> *- Contributions of perceived workload to autonomic changes were more related to 'mental and time demands' than 'physical demands'.*

[§]Corresponding Author: Paulo Farinatti – e-mail: paulofarinatti@labsau.org
Affiliations: [1]Graduate Program in Physical Activity Sciences, Salgado de Oliveira University, Niteroi, RJ, Brazil; [2]Graduate Program in Clinical and Experimental Physiology, University of Rio de Janeiro State, Rio de Janeiro, RJ, Brazil; [3]Graduate Program in Operational Human Performance, Air Force University, Rio de Janeiro, RJ, Brazil; [4]Graduate Program of Movement Science and Rehabilitation, UniEVANGÉLICA, Anápolis, GO, Brazil; [5]Graduate Program in Sports and Exercise Sciences, University of Rio de Janeiro State, Rio de Janeiro, RJ, Brazil.

Conclusion: Greater perceived workload during military transport flights increased sympathetic and lowered parasympathetic modulation but did not influence cognitive performance.

Keywords: autonomic nervous system, Stroop test, NASA-TLX, military aviation, work stress, health.

Resumo

Introdução: O estresse durante a pilotagem de aeronaves influencia a saúde e desempenho dos pilotos. Pesquisas sobre a influência da carga de trabalho durante voos militares sobre esses desfechos são necessárias.
Objetivo: Esse estudo investigou os efeitos da carga trabalho percebida durante voos de transporte militar sobre a modulação autonômica e desempenho cognitivo de pilotos em treinamento da Força Aérea Brasileira.
Métodos: Neste estudo observacional transversal, participaram 15 pilotos (25±1 anos; 222±37 h acumuladas de voo; 47.6±3.9 ml.Kg-1.min-1) realizaram dois voos sucessivos (50-75 min) nas funções de piloto (P1) e copiloto (P2). A carga de trabalho percebida foi avaliada pelo inventário NASA-TLX. A modulação autonômica durante os voos foi avaliada por índices da variabilidade da frequência cardíaca. O desempenho cognitivo antes e após os voos foi comparado pelo Teste de 'Stroop' (palavra-cor).
Resultados: A carga de trabalho dos voos foi moderada (~5 pontos), com contribuição cinco vezes maior da 'demanda mental' *vs*. 'física'. Os voos acarretaram aumentos de 2-3 vezes na modulação simpática, com alterações autonômicas médias 50% maiores em P1 que P2 (Δ max/min, p<0.05): RRi (P1: Δ -189/-199 ms; P2: Δ -164/-177 ms), RMMSD (P1: Δ -24/-25 ms; P2: Δ -16/-18 ms), pNN50 (P1: Δ -19/-20%; P2: Δ -15/-20%), LF (P1: Δ 19/24 u.n.; P2: Δ 19 u.n.), HF (P1: Δ -19/-23 u.n.; Δ P2: -18/-19 u.n.), LF/HF (P1: Δ 4/5; P2: Δ 3/4). Correlações entre NASA-TLX e modulação simpática foram inversas *vs*. 'demanda física' e 'carga total' (r_s= -0.52/-0.63) e direta *vs*. 'demanda mental' (r_s=0.57), o oposto ocorrendo para a modulação parassimpática (r_s=0.47/0.59; r_s= -0.45/-0.47; p<0.05). O desempenho cognitivo permaneceu inalterado e não se correlacionou com os componentes do NASA-TLX.
Conclusão: Uma maior percepção da carga de trabalho durante voos militares de transporte acarretou aumento na modulação simpática e redução parassimpática, mas não influenciou no desempenho cognitivo.

Pontos Chave
- Os efeitos de voos de transporte militar em pilotos novatos foram que houve aumento da atividade nervosa simpática e diminuição da atividade de modulação vagal.
- Carga de trabalho percebida correlacionada com mudanças autonômicas, mas não com desempenho cognitivo.
- Contribuições da carga de trabalho percebida para mudanças autonômicas estavam mais relacionadas a 'demandas mentais e de tempo' do que 'demandas físicas'.

Palavras-chave: sistema nervoso autonômico; Stroop test; NASA-TLX; aviação militar; estresse laboral; saúde.

Effects of Workload in Novice Military Transport Flights on Autonomic Modulation and Cognitive Performance: An Observational Cross-Sectional Study

Introduction

Flying an aircraft demands elevated levels of physical and cognitive abilities required to face aspects related to time constraints, safety threats, and environmental conditions(1). The workload to flight an aircraft result from the balance between pilots' reactions (thoughts, decisions, and behaviors) and stress components (anxiety, altitude changes, displacements, accelerations, cabin pressure, noise, etc.)(2). The complexity of those interactions raises interest on the psychophysical impact of work-related stress during different flight modalities(3-5).

The autonomic nervous system plays a key role in the reactive process to work-related stress(4). The responses for coping with psychophysiological adversity are linked with autonomic dysregulation, characterized by increased sympathetic and/or decreased vagal activity(4). Changes in autonomic control related to flight settings have been reported in military personnel(1,6-9). There is robust evidence suggesting acute autonomic control shift towards increased sympathetic activity in fight military pilots (6,8-10). Exaggerated sympathetic responses may lead to decreasing in cognitive function and vigilance compromising flight safety and effectiveness(1). Moreover, constant autonomic balance disruption may negatively affect homeostasis and predispose to chronic pathological conditions, particularly cardiovascular diseases(11).

Specifically for military transport flights, pilots perform prolonged missions with high monthly frequency. They work in narrow spaces, attached to belts, helmets, and gloves, and support high sound levels or darken light. Under those conditions, they must monitor the outside environment and maintain communication with land control, which demands high attention levels. Despite those stressful peculiarities, research on autonomic control during transport flights is scarce, as well as data on its relationships with workload and/or operational performance. We found only two studies on the issue. One of them reporting decreased heart rate variability (HRV) along with vagal withdrawal and sympathetic activation *vs*. baseline during commercial flights(12), and the other suggesting that autonomic control could be used as a marker of mental workload in full-mission flight simulations performed by commercial pilots(13). Trials describing the autonomic changes in military transport flights could not be found, which is suggestive of a gap in the literature.

The Brazilian Air Force (BAF) ('Força Aérea Brasileira': FAB) is responsible for the defense of an extensive territory performed by a limited staff, which has consequences in terms of the frequency and duration of flights. Thus, studies addressing the factors associated to operational performance and health of FAB pilots are necessary. Given, the present study investigated the association of perceived workload with autonomic modulation and cognitive performance during military transport flights in novice FAB transport pilots. We hypothesized that the stress imposed by transport flight conditions would elicit unfavorable changes in autonomic control. Those changes were expected to relate to the perceived workload and negatively influence the pilots' cognitive performance.

Methods

Study design and subjects

This was an observational cross-sectional study with a convenience sample, in which took part 15 military transport pilots under training at the FAB Anápolis base (GO, Brazil). Pilots were male, aged between 23-25 years (average 24.7 ± 1.0 years), and attended flight instructions in 'C-95 Bandeirante' aircrafts (airdropping paratroopers). They should be classified as fit at the annual health inspection and have at least 200 h of flight experience.

Ethical aspects

All participants provided informed consents. The study was conducted according to the principles laid at the Declaration of Helsinki, and the protocol gained approval from the ethical boards of involved institutions, Pedro Ernesto University Hospital (2.356.970) and Galeão Air Force Hospital (2.532.858).

Study variables

The main outcomes were the autonomic modulation – reflected by heart rate variability (HRV); perceived workload – reflected by the NASA-TLX inventory(14,15); and cognitive performance – reflected by the Stroop Effect test(16). Cognitive performance and perceived workload were the exposure variables for autonomic modulation. For cognitive performance, the perceived workload was the exposure variable. Sample characteristics included age, anthropometric variables and estimated cardiorespiratory fitness. Environmental variables (pressure, temperature, humidity, flight altitude, and duration) were also recorded for a better characterization of the conditions of flight missions.

Autonomic modulation

The autonomic modulation (main outcome) was evaluated using HRV indices(17). Time series of RRi were recorded during 10 min at rest (Polar RS800cx, PolarTM, Kempele, Finland) and throughout the flights, and 5-min time windows were selected for analysis (one at rest and two in each flight, after takeoff and before landing). After removing artifacts, HRV indices were analyzed using the KubiosTM software (University of Kuopio, Kuopio, Finland). The following indices were obtained in the time domain: average of RRi; total power; standard deviation of RR (SDNN); squared root of the mean squared differences of successive RR (rMSSD); and percentage of successive RR differing more than 50 ms (pNN50). These indices are interpreted as markers of vagal activity within short periods(17). In the frequency domain, bands corresponding to low frequency (LF: 0.04–0.15 Hz) and high frequency (HF: 0.15–0.40 Hz) were calculated, and LF:HF ratio reflected the sympathovagal balance(17). Spectral values were expressed as normalized units (n.u.).

Cognitive performance

Cognitive performance (outcome variable, and exposure for autonomic modulation) was assessed using the Stroop Color and Word TestTM (SCWT)(16), which consists of a neuropsychological test evaluating the ability to inhibit cognitive interference that occurs when the processing of a specific stimulus feature precludes the simultaneous processing of a second stimulus attribute(16,18). In commercial and military flight settings, it has been often used to investigate executive features related to awareness control, visual perception, cognitive flexibility, smooth intelligence, and attention(18). In the present study, the application of SCWT followed the recommendations of computerized tests, which have been reported to exhibit equivalent or greater reliability than analogical versions(19). The SCWT was applied to assess pilots' cognitive performance before and immediately after flight situations. Outcomes were the number of correct hits and total testing duration.

Workload

The perceived workload (exposure variable) was evaluated using the NASA-TLX test. The NASA-TLX has been widely applied to estimate the perceived workload, either in flight simulators(20-22), or actual civil(23) and military(24) flights. The inventory consists of a self-assessment technique (inventory) in which respondents subjectively rate their workload along six different sub-scales: mental demand, physical demand, temporal demand, performance, frustration, and effort(15). In the first part of the evaluation, the respondents choose weights for each of the six dimensions, therefore defining their relative contribution to the perceived workload. The six dimensions form pairs generating different combinations(14,15). The inventory requires respondents to rank-order the six sub-scales in terms of which of them better characterizes how they perceive the workload. Respondents circulate the dimension that, in their opinion, contributed more to the workload within a given condition. Each dimension may assume a value (or weight) ranging from 0 (not relevant) to 5 (more relevant than any other dimension), equivalent to the number of times a given dimension is circulated. The overall workload is calculated by multiplying each workload rating *vs.* corresponding weights to obtain an adjusted rating and then dividing this result by 15. In short, the NASA-TLX provides seven measures of workload: six individual measures plus the overall workload measure. A complete description of the instrument and its application is available elsewhere(15).

As highlighted by a retrospective study based on the first 20 years of the NASA-TLX application, a limitation of the instrument is the lack of cutoff points for the perceived workload(25). A previous review including 237 trials that used the inventory proposed a median value of 49.9 points for the overall score(26). However, both studies acknowledged that the NASA-TLX interpretation is mostly subjective and comparative, depending on the characteristics of the evaluated task and relative weight of physical, mental, and volitional components(25,26).

Anthropometric variables

Anthropometric variables described the study sample. Skinfolds were measured (triceps, subscapular, mid-axillary, suprailiac, pectoral, abdomen, and quadriceps) and used to estimate body fat(27). The body mass index (BMI) was calculated from measurements of height and body mass (Kg/m2). The waist circumference was measured using a flexible tape (cm).

Cardiorespiratory fitness

The cardiorespiratory fitness was estimated by the Montreal Track Test(28), which determines the speed associated with the volume of oxygen maximum uptake (VO_2max). Individuals started running at 7 km/h, with speed increments of 1 km/h each 2 min until exhaustion. The highest speed in a complete 2-min stage (maximal aerobic speed, MAS) and total test duration were recorded as outcomes. The VO_2max was estimated as MAS x 3.5 as ml.Kg-1.min-1.

Procedures

Data collection occurred within a week between October and November of 2019. Participants were instructed to abstain from physical exercise, alcohol, soft drinks, and caffeine in the 24 h preceding the assessments. All procedures took place in the morning (8 to 11 a.m.), to minimize potential circadian fluctuations in outcomes.

On the first day, participants had RRi assessed at rest, during 10 min in a sitting position. Subsequently, the SCWT was applied, and then two consecutive flights lasting 50- to 75 min were performed. Flights were classified as of 'tactical air transport' mode, involving paratroopers airdrop simulations from 'C-95 Bandeirante' aircrafts. Participants were novice pilots under training flying without an instructor pilot and performed two successive flights with distinct functions in each one of them, either acting as pilots or co-pilots.

The RRi were continuously assessed during the flights, and pilots were instructed to take notes indicating the moments of take-off and landing. Immediately after the flights, the SCWT was reapplied, and the overall perceived workload was estimated using the NASA Task Load Index (NASA-TLXTM) inventory. After 24- to 72 h, anthropometric measurements were taken, and participants had their cardiorespiratory fitness indirectly estimated through the University of Montreal Track test. Figure 1 summarizes the study design.

Statistical Analysis

Data normality of continuous variables was tested using the Shapiro-Wilk test, and logarithmic transformations were performed whenever necessary. Therefore, results are presented as mean ± standard deviation, unless stated otherwise. Differences between conditions regarding changes (deltas) in HRV indices were tested by 2-way repeated-measures ANOVA (RM ANOVA), followed by Fisher post hoc verifications in the event of significant F ratios. Pre *vs*. post-flight differences for SCWT outcomes (number of hits and reaction time) were tested by paired t-tests. Associations between NASA-TLX dimensions *vs*. cognitive performance and HRV indices were tested by Spearman correlations. Calculations were performed using the SPSS Statistics 25 software (IBMTM Inc., Chicago, IL, USA). In all cases, the significance level was set at $P \leq 0.05$.

Results

Pilots attended flight instructions in 'C-95 Bandeirante' aircrafts (airdropping paratroopers). Fifteen military transport pilots under training at the FAB Anápolis base (GO, Brazil) participated in the study. They were all male, aged between 23-25 years (average 24.7 ± 1.0 years), and had at least 200 h of flight experience (222±37 h). The duration of flights mean was of 65.2 min (50 to 75 min), with cruising altitudes of 4,800 feet (1,463 m). The cabin temperature mean was of 38º C (36 to 39º C), and air humidity was of 35% (32 to 38%). Participants had alternate functions, operating as pilots and co-pilots in the two airborne flights. Sample characteristics are summarized in Table 1.

The group of pilots was homogeneous regarding age, body mass and composition, and cardiorespiratory fitness (CV < 10%). The following scores were obtained in the subscales of the NASA-TLX [median (interquartile range)]: a) Mental demand [21 (16-28)]; b) Physical demand [4 (1-6)]; c) Time demand [16 (7.5-29.5)]; d) Performance [6 (4.5-8)]; e) Frustration [0 (0-1)]. Those scores corresponded to an overall workload of 4.8 (3.7-5.3), with major contributions of the subscales 'mental demand', 'time demand', and 'effort'. Regarding SCWT, no significant difference pre- *vs*. post-flights has been detected in the number of hits (71.5 ± 0.7 *vs*. 71.0 ± 1.1; p = 0.11) or testing duration (480.3 ± 56.9 *vs*. 485.0 ± 71.6; p = 0.79).

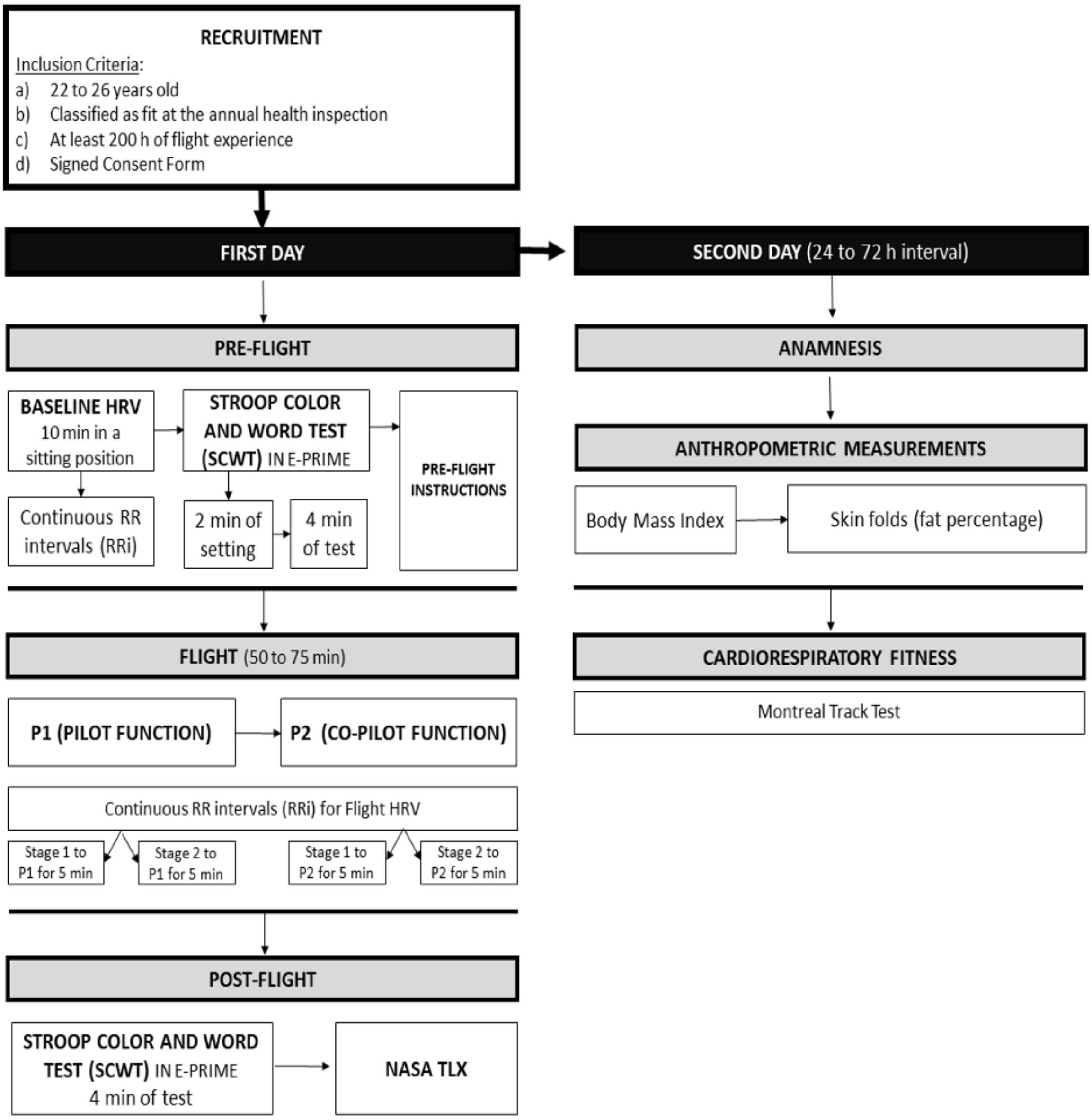

Figure 1 – Study design.

Table 2 presents HRV indices. Significant increases in HR and decreases in RRi and rMMSD *vs*. resting condition occurred in the two flights and functions (pilot and co-pilot). Total power and SDNN were lower when participants operated as pilots *vs*. co-pilots. Consistently, Ln(LF) increased, and Ln(HF) decreased during all flights and functions, resulting in greater sympathovagal balance (LF:HF) *vs*. resting measurements. This sympathetic predominance tended to be greater when participants flew as pilots than co-pilots.

Table 3 shows results of Spearman correlations of perceived workload with changes in HRV indices. Fluctuations in autonomic modulation were significantly related to subscales physical (physical

Table 1 – Sample characteristics (n=15)

Variable	**Mean ± SD**	**CV (%)**
Age (years)	24.7 ± 1.0	4.0
Body Mass (Kg)	75.4 ± 7.5	9.9
Height (cm)	176.6 ± 5.8	3.3
BMI (Kg/m2)	24.2 ± 1.9	8.0
∑ Skinfolds (mm)	402.2 ± 42.2	10.5
% Fat	16.1 ± 4.7	29.2
Waist Circumference (cm)	80.6 ± 3.6	4.5
Montreal Protocol		
Final HR (bpm)	198.8 ± 14.1	7.1
MAS (Km/h)	13.6 ± 1.1	8.2
Distance (m)	2464.3 ± 490.0	19.9
Estimated VO2max (ml.Kg-1.min-1)	47.6 ± 3.9	8.2

BMI: Body Mass Index; **MAS**: Maximum aerobic speed; **VO_2max**: maximal oxygen uptake; **SD**: standard deviation; **CV**%: coefficient of variation [(SD ÷ mean) x 100].

Table 2 – Heart rate variability indices during flights and functions (n = 15)

	Rest	**Flight 1 Pilot**	**Flight 2 Pilot**	**Flight 1 Co-Pilot**
HR (bpm)	73.5±10.4	95.2±13.2*	96.7±12.3*	93.4±12.5*
Rri (ms)	829.9±109.4	641.2±83.3*	630.5±78.1*	652.7±82.3*
Total Power (ms2)	2610.9±1645.4	1020.9±748.5*	1200.7±1077.2*	2165.5±1408.2#
rMMSD (ms)	43.7±17.9	19.1±9.5*	19.7±9.6*	25.4 ±10.2*
SDNN (ms)	49.4±17.1	30.6±11.1*	31.9±12.7*	44.0 ±13.2#ϕ
pNN50 (%)	23.2±16.1	3.8±5.0	4.3±5.7	7.3±6.5
Ln(LF) (n.u.)	63.4±12.4	86.1±6.9*	82.4±10.4*	82.8±6.2*
Ln(HF) (n.u.)	36.5±12.4	13.8±6.9*	17.5±10.4*	17.2±6.2*
LF/HF (n.u.)	2.4 ± 2.0	7.9±4.4*	6.4±3.7*	5.7±2.7*#

HR: heart rate; **Rri**: RR intervals; **rMSSD**: squared root of the mean squared differences of successive RR intervals; **SDNN**: standard deviation of Rri; **pNN50**: percentage of successive RR differing more than 50 ms; **LF**:– Low Frequency band; **HF**: High Frequency band; **LF/HF**: ratio between LF and HF; **Ln**: base e logarithm; **n.u.** – normalized unity. *: Significant difference *vs.* rest ($p < 0.00$); **#**: Significant difference *vs.* Flight 1 – Pilot ($p < 0.05$); #: Significant difference *vs.* Flight 2 Pilot ($p < 0.05$).

Table 3 – Spearman correlations of perceived workload sub-scales with heart rate variability (HRV) indices (n = 15)

	Mental demand	Physical demand	Time demand	Performance	Effort	Frustration	Σ	Overall workload
Δ1 RR (Pilot)	0.00	0.53 *	-0.05	-0.16	0.04	-0.50 *	-0.02	-0.05
Δ2 RR (Pilot)	-0.05	0.54 *	-0.06	-0.14	0.12	-0.43	0.02	-0.01
Δ1 RR (Co-pilot)	-0.08	0.52 *	-0.01	-0.10	0.11	-0.37	0.09	0.07
Δ2 RR (Co-pilot)	-0.06	0.47 *	-0.04	-0.10	0.09	-0.34	0.05	0.03
Δ1 RMSSD (Pilot)	0.16	0.53 *	-0.30	-0.30	0.07	-0.19	0.03	-0.01
Δ2 RMSSD (Pilot)	0.17	0.42	-0.42	-0.35	0.08	-0.12	-0.08	-0.12
Δ1 RMSSD (Co-pilot)	0.16	0.34	-0.17	-0.29	0.10	-0.03	0.13	0.11
Δ2 RMSSD (Co-pilot)	0.15	0.35	-0.08	-0.34	0.13	-0.06	0.21	0.18
Δ1 SDNN (Pilot)	0.33	0.34	-0.31	-0.38	-0.10	0.04	0.08	0.05
Δ2 SDNN (Pilot)	0.23	0.13	-0.44	-0.35	0.05	0.12	-0.06	-0.10
Δ1 SDNN (Co-pilot)	0.19	0.32	-0.18	-0.29	-0.07	0.02	0.07	0.04
Δ2 SDNN (Co-pilot)	0.23	0.07	0.04	-0.34	0.09	0.08	0.28	0.26
Δ1 pNN50 (Pilot)	0.40	0.39	-0.47 *	-0.37	0.14	-0.15	0.05	0.01
Δ2 pNN50 (Pilot)	0.33	0.37	-0.45 *	-0.29	0.22	-0.16	0.05	0.01
Δ1 pNN50 (Co-pilot)	0.38	0.26	-0.36	-0.32	0.16	-0.06	0.13	0.09
Δ2 pNN50 (Co-pilot)	0.38	0.34	-0.34	-0.40	0.12	-0.10	0.12	0.08
Δ1 PT (Pilot)	0.37	0.28	-0.22	-0.46 *	-0.18	0.03	0.10	0.07
Δ2 PT (Pilot)	0.29	-0.01	-0.27	-0.20	0.12	0.19	0.16	0.13
Δ1 PT (Co-pilot)	0.21	0.18	-0.26	-0.17	-0.08	0.22	0.08	0.06
Δ2 PT (Co-pilot)	0.35	-0.01	0.15	-0.49 *	-0.23	0.17	0.28	0.29
Δ1 LF (Pilot)	-0.33	-0.25	0.07	0.06	-0.50 *	0.25	-0.41	-0.42
Δ2 LF (Pilot)	-0.32	-0.53 *	0.37	0.10	-0.13	0.21	-0.03	-0.04
Δ1 LF (Co-pilot)	-0.12	-0.36	-0.02	0.33	-0.30	0.36	-0.24	-0.22
Δ2 LF (Co-pilot)	-0.02	-0.13	-0.25	0.01	-0.42	0.12	-0.53 *	-0.54 *
Δ1 HF (Pilot)	0.33	0.25	-0.07	-0.06	0.50 *	-0.25	0.41	0.42
Δ2 HF (Pilot)	0.34	0.51*	-0.37	-0.12	0.11	-0.17	0.04	0.05

(Continue)

	Mental demand	**Physical demand**	**Time demand**	**Performa nce**	**Effort**	**Frustratio n**	**Σ**	**Overall workload**
Δ1 HF (Co-pilot)	0.11	0.40	-0.01	-0.34	0.39	-0.40	0.19	0.19
Δ2 HF (Co-pilot)	0.02	0.13	0.25	-0.01	0.42	-0.12	0.53 *	0.54 *
Δ1 LF/HF (Pilot)	0.18	0.18	-0.19	-0.43	-0.09	0.02	-0.06	-0.08
Δ2 LF/HF (Pilot)	0.02	-0.29	0.05	-0.25	-0.03	0.16	0.00	-0.01
Δ1 LF/HF (Co-pilot)	0.35	-0.23	-0.13	-0.03	0.14	0.16	0.16	0.16
Δ2 LF/HF (Co-pilot)	0.57 *	0.21	-0.22	-0.63 *	-0.16	-0.28	-0.15	-0.17

Δ1: variation *vs.* rest in flight 1; **Δ2**: variation *vs.* rest in flight 2; **S- sum**: RR- Interval between two R waves; **RMSSD**- root mean square of successive RR interval differences; **SDNN**- Standard deviation from every interval from normal to normal; **pNN50**- Percentage from adjacent RR intervals with difference in length bigger than 50ms; **PT**- total output; **LF** – Low Frequency band; **HF**- High frequency band; **LF/HF**- ratio between LF and HF; * - Significant difference (p<0.05).

Table 4 – Spearman correlations between NASA-TLX sub-scales and Stroop Color Word Test outcomes (n = 15)

	Mental demand	**Physical demand**	**Time demand**	**Performance**	**Effort**	**Frustration**	**Overall workload**
no. of hits (post-flight)	-0.19	0.23	0.08	-0.22	-0.47	-0.02	-0.25
Δ no. of hits (Post *minus* pre)	-0.15	0.20	0.26	-0.07	-0.07	-0.15	0.14
Test duration (post-flight)	-0.23	0.25	0.17	0.12	-0.21	-0.08	-0.06
Δ Test duration (Post *minus* pre)	0.07	-0.09	0.01	0.08	-0.16	-0.05	-0.16

p > 0.05 in all cases.

demand, performance, and effort) and mental workload, especially when participants flew as pilots. Finally, Table 4 shows that significant correlations of perceived workload with cognitive performance could not be detected.

Discussion

This cross-sectional study investigated whether the stress during military transport flights provoked unfavorable changes in autonomic modulation and tested the association of this fluctuation with the perceived workload and cognitive performance. To the best of our knowledge, this is the first study to address this issue in Brazilian pilots. The main findings were a) In comparison with resting conditions, HRV indices reflecting sympathetic modulation increased, while those related to parasympathetic modulation decreased, particularly when participants flew as pilots *vs*. as co-pilots; b) Changes in autonomic modulation correlated with perceived workload in physical and mental components; c) Cognitive performance – measured before and after flights, remained unaltered and associations with autonomic changes were not detected.

Pilots deal with extremely specific activities, which demands precise control over complex systems and involves distinct levels of operation and interconnected tasks(25,26,29). The workload perception is recognized to influence fatigue, attention, and decision-making ability during flights in civil and military aviation(12,23,26). The workload in aviation results from the relationship between task constraints, interface, instruments, and environment, in addition to the operator's work capacity(23-25).

In this study, transport flights of approximately 60 min produced an average score of 4.8 points in the NASA-TLX, which can be classified as low workload when considering data from previous studies. Regarding military transports, we could find a study, a master's degree dissertation that evaluated FAB pilots who performed distinct types of strategic transport flights, also using the 'C-95 Bandeirante' aircraft(30). The mean of the scores of overall perceived workloads were 16.66 points for daytime and nighttime adaptation/readaptation flights, 11.46 points for advanced instrument flights, 10.03 points for navigation flights, 11.49 points for search and rescue flights, and 9.39 for air control flights, which are substantially greater than our findings. Despite of the difference in scores' magnitudes, there was similarity to our data: perceived workload scores were higher in pilots *vs*. co-pilots. The difference may be explained because in Baumer's study(30) the duration of flights reached a mean of 6.5 h whereas in the present study the mean of duration of flights was of 1 h. This helps to explain the differences in overall scores since the flight duration seems to influence the perceived workload(26,27). Additionally, in Baumer`s study(30) the flights were sometimes performed by night and involved more complex tasks (as 'search and rescue') *vs*. the 'airdrop' transport missions presently evaluated.

Our data showed that the dimension 'mental and time' presented greater scores compared with the dimension 'physical'. 'Mental demand' translates the demand in terms of awareness and task focus, 'time demand' refers to time pressure to perform a task, and 'physical demand' relates to physical effort/fatigue. At least one prior study using the NASA-TLX found a predominance of mental over physical demands after flights lasting 3 h in helicopter pilots(31). It is therefore possible that in relatively short flights, cognitive demands have a greater repercussion on general workload perception. In more prolonged flights, the physical strain may overcome mental components since piloting sometimes requires considerable force to counteract mechanical resistances. Comparative studies on the perceived workload elicited by military flights performed in different conditions (aircraft, purposes, duration, etc.) are needed for a better understanding of the relative role of stress-related variables in the perceived workload.

Psychophysiological responses to stress affect autonomic control in tactical work settings, including military personnel(4,5). The autonomic nervous system does not only respond to internal and external stimuli but also contributes to appropriate responses to those challenges(1,4,10). Work-related stress induces neuroendocrine responses including the activation of hypothalamic-pituitary-adrenal axes, adrenal cortex, and medulla(32), which leads to greater sympathetic activity and increased physiological responses when a threat is perceived. When stressors recede, the vagal outflow increases, and the body resumes the homeostatic state. Autonomic control has been shown to associate with several indicators of self-regulatory capacity, coping effectiveness, and impulse control(33). Moreover, increased sympathetic and decreased vagal activity seem to be characteristic features of acute and chronic physical(34) and mental(35) fatigue due to prolonged cognitive workload. Overall, the accumulated evidence is suggestive that the greater the fatigue symptoms, the more the sympathovagal balance increases(7,10).

In that context, the analysis of HRV is consolidated to assess changes in autonomic modulation due to fatigue-related stress. Standard HRV scores correlate with mental and physical stress, fatigue, mood, anxiety/fear, tension, cognitive decline, and muscle/joint pain(10,36). The HRV reflects the balance between sympathetic and parasympathetic outflows and is modified by cognitive, attentional, emotional, or physical stimulus(36). The use of HRV has been also applied to autonomic changes during military assignments in general(4,5), including flight missions(6,37). A shift of autonomic control towards sympathetic outflow has been reported in military fighter pilots. One of the first studies on this matter(9) reported that the magnitude of urine excretion of catecholamines in attack pilots depended on the nature of the flights performed (lesson, preparation, or mission). Otsuka et al.(7) ratified these data, by showing an increase in the urine adrenaline of experienced pilots after strenuous aerobatic flight demonstrations and air-to-air combat maneuvering.

A high post-flight ratio of adrenaline was acknowledged as a normal adaptation to flight workload, even for experienced jet pilots. Sauvet et al.(1) described the kinetics of HRV indices within flights lasting 3.5 h performed by military novice pilots (mean flight experience of 116 h), and over 24-h recovery. Correlations between HRV and vigilance parameters have been also calculated. Increased sympathetic parallel with vagal withdrawal occurred during the flights, and this unbalance remained for 5 h after landing. The impaired vigilance after flights did not correlate with HRV fluctuations. Sukhoterin & Pashchenko(6) investigated the autonomic reactivity in pilots of high-maneuver aircrafts who varied in age and flying time (56 pilots of fighter and assault aircrafts). A consistent increase in sympathetic outflow was again detected, which persisted in the inter-flight periods.

Finally, a recent study(37) investigated HRV, anxiety, perceived exertion, and self-confidence responses during actual and simulated air-air missions in experienced jet pilots. A reduction in RRi and increasing in perceived exertion occurred only in the real flight situations. Similar autonomic responses have been reported during flight situations eliciting lower psychological strain in comparison with air combat missions or high-performance acrobat maneuvers. Lowered HRV along with vagal withdrawal and sympathetic activation have been found during commercial flights, and autonomic cardiovascular control has been suggested as an alternative to differentiate mental workload during flights(13,38). However, as abovementioned trials with military transport pilots are very scarce. We found a single study monitoring fighter pilots during instrument approach similar to transport flight conditions, which observed increases in sympathetic and decreases in parasympathetic modulation proportional to the complexity of cognitive workload imposed by the task(38).

The influence of task specificity on autonomic responses has been acknowledged. A recent systematic review concluded that autonomic and cardiovascular chronic stress among soldiers would be modulated by their background and specific training(4). Moreover, the magnitude of autonomic changes would suffer the influence of the nature of performed tasks and specific stressors related to soldiers' units. This concurs with the present data, indicating that greater increases in sympathetic and decreases in parasympathetic outflows when participants operated as pilots *vs*. co-pilots. Moreover, our results are suggestive that autonomic variations were influenced by the workload perception during flights, which are in theory greater in pilots than co-pilots. These findings give room to speculate that this premise could be also applied to flight phases since they elicit different stress levels. In this sense, a prior study in a Boeing 747-400 flight simulator(39) reported that peaks of heart rate occurred during takeoff (83.2 bpm, Δ 14.2 bpm *vs*. rest) and landing (88.6 bpm, Δ 18.8 bpm *vs*. rest). This segmented analysis was not performed in our study, but significant increases in heart rate were observed, with mean peak values of 95.2 ± 13.2 bpm (first flight) and 96.7 ± 12.3 bpm (second flight) in pilots, and of 91.7 ± 12.5 bpm (first flight) and 93.4 ± 12.5 bpm (second flight) in co-pilots *vs*. 73.5 ± 10.4 bpm at rest. In all cases, increases in HRV (reflected by lowered RRi) correlated with the 'physical demand' component of perceived workload. It is possible that isolated changes in heart rate reflect the physical effort during flights, which did not happen significantly with other components of perceived workload.

The relationship between changes in autonomic control and the stress/fatigue imposed by piloting would be so close, that a previous study suggested that the LF:HF ratio (reflecting the sympathovagal balance) might be used to estimate the physical workload during flight tasks(8) and our data showed that the total effort of the perceived workload significantly correlated with fluctuations in LF:HF. Additional research is needed to ratify the potential applicability of HRV as a marker of physical strain in military flights.

Continuous disruption of the balance between sympathetic and parasympathetic outflows may lead to chronic autonomic dysfunction, with harmful health consequences as increased cardiovascular risk(11). The monitoring of HRV may provide information about the psychophysiological responses of tactical personnel during their activities and throughout recovery(5). Autonomic dysfunction seems to be frequent among the military(4). In the case of pilots, continuous exposure to flight stress may contribute to autonomic imbalance. The study by Sukhoterin and Pashchenko(6) with pilots of high-maneuver aircrafts demonstrated that sympathetic increases were not always completely restored before the subsequent flights so that the pre-stress state in pilots with a flying time over 1000 h frequently turned into chronic autonomic dysfunction. This concurs with data from Sauvet et al.(1), showing that increases in sympathovagal balance persisted in novice fighter pilots throughout 5-h recovery. Considering the Brazilian territory extension and the relatively limited number of military transport pilots, the duration and frequency of flights are generally high, which might have a chronic impact on their autonomic nervous system and cardiovascular health. This aspect should be considered in the planning of pilots' routine and within their periodic health evaluation and the monitoring for detection of acute (post-flight) and chronic autonomic disorders, which may represent an indirect sign of accumulated negative effects of systematic flight overloads upon the autonomic nervous system, and therefore of many organic systems responsible for adequate psychophysical responses to flight demands.

Strong points and limitations of the study

The major strength of the present study refers to the originality of data given the lack of research investigating operational skills and the health impact of flight missions in Brazilian transport military pilots. We could not locate prior studies evaluating the workload perception and its potential impact on autonomic control and cognitive performance in this modality of military flights. Our results contribute to the current knowledge by suggesting that those flights might provoke autonomic disruption. The continuous exposure of pilots to this condition should be considered in operational planning and regular health evaluations.

On the other hand, this study has limitations. The sample size was relatively small and composed of novice pilots. Besides the low statistical power limiting comparisons, the extrapolation of our data to experienced pilots should be made with caution. Two-hundred flight hours is low and reflects little flying aircraft experience, indicating that the evaluated aviators probably have not achieved flight skills related to and control habits. The accumulated experience may improve the performance during flights, reducing the workload perception and therefore the overall stress.

Another limitation was that the breathing rate was not controlled. Thus, respiratory sinus arrhythmia that may occur during RRi assessments was not evaluated. The duration of flights was approximately 60 min and performed in training settings, which is perhaps not representative of actual longer missions performed by military transport pilots. The extrapolation of the present data to flights of different durations, purposes, and characteristics (physical and mental workloads) should be made with caution. Finally, only the overall workload perception was assessed at the end of each flight, precluding segmented analyzes of the relationship between workload and autonomic control.

Conclusion

This study investigated the changes in autonomic modulation during military transport flights performed by novice FAB pilots, and their potential relationship with the perceived workload and cognitive performance. The hypothesis that military transport flights performed by novice FAB pilots would induce an increase in sympathetic and decrease in vagal modulation was confirmed. Those responses were more pronounced in pilots than co-pilots, which reinforces the role of task specificity in work-related stress. Accordingly, correlations between autonomic changes *vs*. physical and mental components of NASA-TLX were mainly detected when participants operated as pilots. On the other hand, the premise that greater perceived workload during transport flights would negatively influence pilots' cognitive performance was not confirmed. Flights with relatively short duration may not elicit enough work-related stress to compromise cognitive features evaluated by the SCWT, as selective awareness or information processing speed.

Given the exploratory nature of the present study, further research to confirm our results is warranted, including flight missions with varying complexities and pilots with different ages and experience levels. Using novice pilots may have helped to detect significant differences in autonomic control. More experienced pilots most likely would have had less sympathetic stimulation and reaction to these short training flights that the students. Additionally, longitudinal follow-ups should be developed focusing on the effects of prolonged exposition to flight-related autonomic disruption on the cardiovascular health of military transport pilots. This would be useful to define training and operational procedures, as interventions to manage the acute autonomic stress or optimal recovery periods between flight missions.

Acknowledgments

We thank the Brazilian Air Force Anápolis Base (GO) staff for the support during this study.

Conflict of interests

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report.

Funding statement

This study was partially supported by grants from the Brazilian Higher Education Improvement Coordination (CAPES) (88887.387712/2019-00, PROCAD-DEFESA, recipient PF), Brazilian Council for Technological and Scientific Development (CNPq) (303629/2019-3, recipient PF; 308608/2019-4, recipient WDM), and Carlos Chagas Filho Foundation for Research Support in the State of Rio de Janeiro (FAPERJ) (E-26/202.880/2017, recipient PF).

References

1. Sauvet F, Jouanin JC, Langrume C, et al. Heart rate variability in novice pilots during and after a multi-leg cross-country flight. *Aviation, Space, and Environmental Medicine* 2009; 80: 862-869. 2009/10/13. DOI: 10.3357/asem.2531.2009.
2. Chandra A and Conry S. In-flight Medical Emergencies. *Western Journal of Emergency Medicine* 2013; 14: 499-504. 2013/10/10. DOI: 10.5811/westjem.2013.4.16052.
3. Boyd JE, Patterson JC, and Thompson BT. Psychological test profiles of USAF pilots before training *vs*. type aircraft flown. *Aviation, Space, and Environmental Medicine* 2005; 76: 463-468.
4. Bustamante-Sánchez A, Tornero-Aguilera JF, Fernández-Elías VE, et al. Effect of Stress on Autonomic and Cardiovascular Systems in Military Population: A Systematic Review. *Cardiology Research and Practice* 2020; 2020: 7986249. DOI: 10.1155/2020/7986249.
5. Tomes C, Schram B and Orr R. Relationships Between Heart Rate Variability, Occupational Performance, and Fitness for Tactical Personnel: A Systematic Review. *Frontiers in Public Health* 2020; 8: 583336. DOI: 10.3389/fpubh.2020.583336.
6. Sukhoterin A and Pashchenko P. Structural and functional reserves of the autonomic nervous system in pilots of high-maneuver aircrafts. *Human Physiology* 2016; 42: 731-735. DOI: 10.1134/S0362119716070173.
7. Otsuka Y, Onozawa A, Kikukawa A, et al. Effects of flight workload on urinary catecholamine responses in experienced military pilots. *Perceptual and Motor Skills* 2007; 105: 563-571. 2007/12/11. DOI: 10.2466/pms.105.2.563-571.
8. Skibniewski FW, Dziuda Ł, Baran PM, et al. Preliminary results of the LF/HF ratio as an indicator for estimating difficulty level of flight tasks. *Aerospace Medicine and Human Performance* 2015; 86: 518-523. DOI: 10.3357/AMHP.4087.2015.
9. Svensson E, Thanderz MA, Sjoberg L, et al. Military flight experience and sympatho-adrenal activity. *Aviation, Space, and Environmental Medicine* 1988; 59: 411-416. 1988/05/01.
10. Okawa N, Kuratsune D, Koizumi J, et al. Application of autonomic nervous function evaluation to job stress screening. *Heliyon* 2019; 5: e01194. 2019/03/07. DOI: 10.1016/j.heliyon.2019.e01194.
11. Thayer JF, Yamamoto SS and Brosschot JF. The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. *International Journal of Cardiology* 2010; 141: 122-131. 2009/11/17. DOI: 10.1016/j.ijcard.2009.09.543.
12. Oliveira-Silva I, Leicht AS, Moraes MR, et al. Heart Rate and Cardiovascular Responses to Commercial Flights: Relationships with Physical Fitness. *Frontiers in Physiology* 2016; 7: 648. 2017/01/14. DOI: 10.3389/fphys.2016.00648.
13. Backs RW, Lenneman JK and Sicard JL. The Use of Autonomic Components to Improve Cardiovascular Assessment of Mental Workload in Flight. *International Journal of Aviation Psychology* 1999; 9: 33-47. DOI: 10.1207/s15327108ijap0901_3.
14. Noyes JM and Bruneau DP. A self-analysis of the NASA-TLX workload measure. *Ergonomics* 2007; 50: 514-519. 2007/06/20. DOI: 10.1080/00140130701235232.

15. Casner SM and Gore BF. *Measuring and Evaluating Workload: A primer*. Moffett Field, CA: NASA, 2010, p.2010.
16. Lezak MD, Howieson DB and Bigler ED. *Neuropsychological Assessment*. 5 ed. New York, NY: Oxford University Press, 2012.
17. Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation, and clinical use. *Circulation* 1996; 93: 1043-1065. DOI: 10.1161/01.CIR.93.5.1043.
18. Arikan ZO, Ertemir D and Keskinkilic C. A norm study of a neuropsychological test battery for evaluating cognitive functions in commercial airline pilots. *Dusunen Adam The Journal of Psychiatry and Neurological Sciences* 2018; 31: 375-388. DOI: 10.5350/DAJPN2018310406.
19. Din NC and Tat Meng EC. Computerized Stroop Tests: A Review. *Journal of Psychology and Psychotherapy* 2019; 9: 1000353. DOI: 10.4172/2161-0487.1000353.
20. Mansikka H, Virtanen K and Harris D. Comparison of NASA-TLX scale, modified Cooper–Harper scale and mean inter-beat interval as measures of pilot mental workload during simulated flight tasks. *Ergonomics* 2019; 62: 246-254. DOI: 10.1080/00140139.2018.1471159.
21. Zheng Y, Lu Y, Jie Y, et al. Predicting Workload Experienced in a Flight Test by Measuring Workload in a Flight Simulator. *Aerospace Medicine and Human Performance* 2019; 90: 618-623. 2019/06/23. DOI: 10.3357/AMHP.5350.2019.
22. Rainieri G, Fraboni F, Russo G, et al. Visual Scanning Techniques and Mental Workload of Helicopter Pilots During Simulated Flight. *Aerospace Medicine and Human Performance* 2020; 92: 11-19. DOI: 10.3357/AMHP.5681.2021.
23. Wanyan X, Zhuang D and Zhang H. Improving pilot mental workload evaluation with combined measures. *Bio-Medical Materials and Engineering* 2014; 24: 2283-2290. 2014/09/18. DOI: 10.3233/BME-141041.
24. Orlandi L and Brooks B. Measuring mental workload and physiological reactions in marine pilots: Building bridges towards redlines of performance. *Applied Ergonomics* 2018; 69: 74-92. 2018/02/27. DOI: 10.1016/j.apergo.2018.01.005.
25. Hart, SG. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 2006; 50(9), 904–908. DOI:10.1177/154193120605000909.
26. Grier, RA. How High is High? A Meta-Analysis of NASA-TLX Global Workload Scores. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 2015; 59(1), 1727–1731. DOI:10.1177/1541931215591373.
27. Siri WE, Brozek J and Henschel A. Body composition from fluid space and density. In: Brozek J and Hanschel A (eds) *Techniques for measuring body composition* Washington, DC: National Academy of Science, 1961, pp.223-244.
28. Leger LA, Mercier D, Gadoury C, et al. The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences* 1988; 6: 93-101. 1988/01/01. DOI: 10.1080/02640418808729800.
29. Gaetan S, Dousset E, Marqueste T, et al. Cognitive Workload and Psychophysiological Parameters During Multitask Activity in Helicopter Pilots. *Aerospace Medicine and Human Performance* 2015; 86: 1052-1057. 2015/12/03. DOI: 10.3357/AMHP.4228.2015.
30. Baumer MH. *Avaliação da carga mental de trabalho em pilotos da aviação militar*. Master Dissertation, Universidade Federal de Santa Catarina (UFCS), Florianópolis, 2003.
31. Bezerra FGV and Ribeiro SLO. Preliminary study of the pilot's workload during emergency procedures in helicopters air operations. *Work* 2012; 41: 225-231. DOI: 10.3233/WOR-2012-0161-225.

32. Miller DB and O'Callaghan JP. Neuroendocrine aspects of the response to stress. *Metabolism* 2002; 51: 5-10. 2002/06/01. DOI: 10.1053/meta.2002.33184.

33. Segerstrom SC and Nes LS. Heart rate variability reflects self-regulatory strength, effort, and fatigue. *Psychological Science* 2007; 18: 275-281. 2007/04/21. DOI: 10.1111/j.1467-9280.2007.01888.x.

34. Tanaka M, Mizuno K, Yamaguti K, et al. Autonomic nervous alterations associated with daily level of fatigue. *Behavioral and Brain Functions* 2011; 7: 46. 2011/10/29. DOI: 10.1186/1744-9081-7-46.

35. Mizuno K, Tanaka M, Yamaguti K, et al. Mental fatigue caused by prolonged cognitive load associated with sympathetic hyperactivity. *Behavioral and Brain Functions* 2011; 7: 17. 2011/05/25. DOI: 10.1186/1744-9081-7-17.

36. Shaffer F, McCraty R and Zerr CL. A healthy heart is not a metronome: an integrative review of the heart's anatomy and heart rate variability. *Frontiers in Psychology* 2014; 5: 1040. DOI: 10.3389/fpsyg.2014.01040.

37. Fuentes-García JP, Clemente-Suárez VJ, Marazuela-Martínez MÁ, et al. Impact of real and simulated flights on psychophysiological response of military pilots. *International Journal of Environmental Research and Public Health* 2021; 18: 787. DOI: 10.3390/ijerph18020787.

38. Mansikka H, Simola P, Virtanen K, et al. Fighter pilots’ heart rate, heart rate variation and performance during instrument approaches. *Ergonomics* 2016; 59: 1344-1352. DOI: 10.1080/00140139.2015.1136699.

39. Lee YH and Liu BS. Inflight workload assessment: comparison of subjective and physiological measurements. *Aviation, Space, and Environmental Medicine* 2003; 74: 1078-1084. 2003/10/15.