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Implementing a Quantified Occupational Health Sensing Platform in the Aviation Sector: an Exploratory Study in Routine Air Traffic Control Work Shifts

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***Abstract*— Occupational stress is a complex process affecting health and performance. Air Traffic Control is a complex and demanding profession. The current study demonstrates the concept of using a biomonitoring wearable platform (BWP), that combines self-report measures with biomarkers, to track stress among Air Traffic Controllers. A wearable ECG device was used to gather continuously medical-grade ECG data along with a mobile app for daily stress perception, symptoms and events annotation. A total of 256 hours of data from 32 routine work shifts and 5 days-off, from 5 ATCs was recorded with 35 tagged events using Heart Rate Variability metrics– AVNN, RMSSD, pNN50 and LF/HF were computed from ECG data and analyzed during a) shifts vs days off; b) events vs non-events and c) before and after working pauses. ATCs showed low levels of chronic stress using self-reports. Results showed that stress symptomatology slightly increase from the beginning to the end of the shift (*Md*=1 to *Md*=2; p<0.05). Statistical significant physiological changes were found between shifts and days off for AVNN and LF/HF (p<0.05), showing higher physiological activation during shifts. A significant reduction of physiological arousal was verified after working pauses, particularly for AVNN and LF/HF (p<0.001). Self-reported data also suggests the same trend (p<0.005). Findings reinforced the discriminatory power of AVNN and LF/HF for short-term stress classification using HRV measurements. Results suggest that the rotating working system, with pause/resting periods included, effective acted as a recovery period.**

***Clinical Relevance*—Results provide important clues to the impact of stress on health, particularly cardiac reactivity and the identification of stress quantitative biomarkers as diagnostic indicators, providing a more reliable source for stress monitoring than currently behavioral or subjective measures. Findings will help on the design of stress management programs and prevention actions in order to avoid the negative effects of stress.**

I. Introduction

According to the World Health Organization nearly half of the world's population is affected by mental illness, namely with stress [1]. The workplace, where we spend at least a third of our time, is a privileged territory to the increase of these problems. Stress can be defined as a process, whereas a situation is perceived as exceeding individual's resources or threatens the person's well-being [2]. Several instruments allow for the understanding of mental stress levels (e.g., Perceived Stress Scale –PSS [3]). However, due to the multifactorial nature of stress, when a threat is perceived, a physiological body response is trigged, and sometimes, when chronic, it could lead to serious health problems. As an example, there is a close link between stress and cardiovascular disease. One of the most accurate signals for discriminating stress is the heart activity. Stress changes the balance of the autonomic nervous system (ANS), that impacts the heart rate directly [4]. Heart Rate Variability (HRV) has been considered as a reliable indicator of physiological stress reactions. However, very little agreement exists in the literature for the most appropriate HRV-based metric for stress events detection and differentiation [5].

The importance of stress topic has been recognized. However, the way stress is being evaluated has several constrains [6]: 1) stress assessments are often cross-sectional and retrospective, failing to screen within-person variations and data collected may be influenced by memory biases; 2) there seems to be a lack of combined tools to assess workplace stress in real time and in an evidenced-based manner; 3) stress is multifactorial with several comorbidities and there is a lack of quantified biomarkers that can serve diagnostic classificatory systems.

Air Traffic Control (ATC) is a very demanding and role complex profession that is widely perceived as being stressful. The core of ATCs is to ensure a safe, ordered and efficient flow of air traffic in the worldwide ATC structure while avoiding collisions between aircrafts [7]. Despite the above mentioned challenges in the current methods used to address stress among working populations, there are also limitations in the assessment of stress among ATCs. Particularly among Portuguese ATCs, the literature is scarce or nonexistent, probably due to the difficulties of accessing these variables among this population in real working conditions. Moreover, current methodologies used to assess stress among ATCs are only based on questionnaires, and stress management only relies on the rotation between working periods and pauses and there is no currently available method to address the effectiveness of this working system to manage stress. Our research team has already conducted two exploratory studies with ATCs in order to assess stress. Results showed that induced stress (using the Trier Social Stress Test and ATC simulators) caused impaired performance, affecting attention and decision-making ability [8,9]. However, it is known that

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assessing stress in laboratory environments is quite different than assessing stress in daily life. Hence, in order to overcome these gaps, this research pretends to evolve the state-of-arte by evaluating stress among ATCs, during real operations using a BWP that combines both physiological data with self-reports, providing a quantified and more accurate approach. It allows a within-person variation analysis, by evaluating the same subjects under different conditions, using stress biomarkers. Our specific goals in this study were 1) obtain an indication of ATCs chronic stress levels; 2) understand stress variations during ATCs shifts and compare it with days off; 3) compare stress levels during ATC shifts specific events and non-events; 4) compare stress levels before and after shifts pauses to understand if the resting period is effective.

II. METHODS

In order to afford a standardized reporting of methodologies investigating HRV in behavioral sciences, our research method will be based on the Guidelines for Reporting Articles in Psychiatry and HRV (GRAPH) [10] (Figure 1).

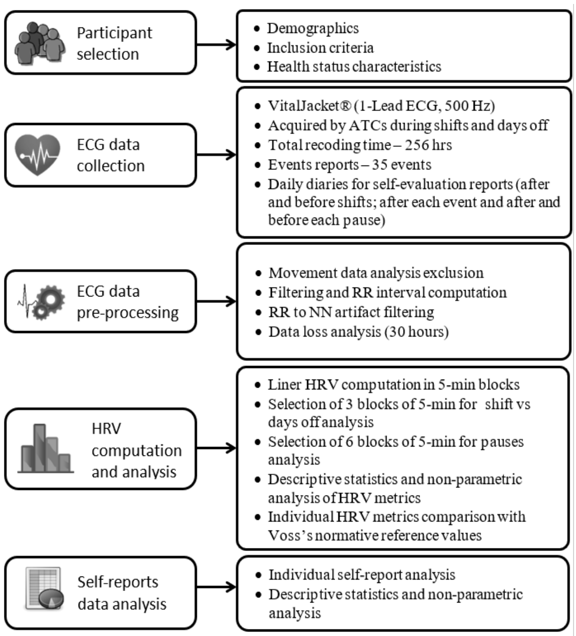

Figure 1. Study method illustration based on GRAPH [10].

A. Dataset description

Five Portuguese area/en-route ATCs (3F, 2M; *M*age= 42.6 ± 3.1), with an average of 16 years (± 1.5) of experience in ATC operations voluntarily participated in this study. The exclusion criteria were participants having a history of cardiovascular disease and/or taking prescription drugs known to affect cardiovascular function. All participants were given a "study kit", that included a wearable ECG device and a mobile phone with a custom-made mobile application with an electronic diary. Participants were monitored during an average of 7 shifts each, balanced between morning, afternoon and night shifts (6h to 8h each) and a day off. A total of 32 shifts were analyzed including 35 events reported in a total of 212 hours of ECG collected during shifts. Moreover, a total of 44 hours of ECG were analyzed for days off, resulting in a sum of 256 hours of ECG data analyzed (Fig.1). The approval to carry out this experimental procedure involving human subjects was obtained by the University of Porto Ethics Committee.

B. Wearable vital signal platform

For data acquisition system, a proprietary quantified occupational health platform was used, including: A) wearable chest patch (based on VitalJacket® technology) with a patented technology [11] able to continuously acquire medical-grade ECG (MDD93/ 42/EEC), actigraphy, temperature. Data is stored on a SD memory card and can also send it to a personal computer or a mobile device using Bluetooth communication. The ECG data is recorded using 1-lead system with a sampling rate of 500 Hz. This device enables a continuous comfortable recording without interfering with the user's daily activities (Fig.2–(1)); B) a custom made android mobile application (App) including an electronic diary, that allows to synchronize event marking and reporting. It pairs via Bluetooth with the wearable ECG device, enabling to synchronize the annotation of events in all connected devices and in the ECG trace using a functionality named "Radiobutton" (Fig.2–(2)); C) all data is then exported into an annotated Database for processing and analysis (QRS detection and HRV), always ensuring the synchronization between the events information and the data collected by the wearable (Fig.2– (3)-(5)).

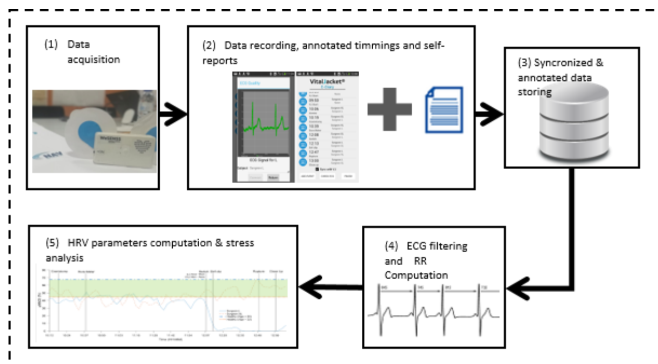

Figure 2. Illustration of system´s architecture.

C. Self-assessment tools

Demographic and medical surveys were used to assess participants' current health state. For chronic stress analysis, PSS was used. The PSS is a 14-item scale ranging from `0-never' to `4-very often'. Participants were asked to indicate how often they felt or thought a certain way in the past month. Scores range from 0 to 56, with higher scores indicating more stress [3]. The electronic diaries included a stress symptoms questionnaire [12], that contains four questions related to physical aspects and four questions related to cognitive aspects of stress (ranging from '1 – not felt at all' to '5 – extremely felt'). These questions were answered at the beginning and at the end of the shift, aiming to evaluate whether there were changes in stress symptoms experienced. Additionally, a Visual Analogue Scale (VAS) [13] was used before and after each event and working pause and before and after each shift to assess perceived stress levels on a 10 levels scale (ranging from '0 - None' to '10 - As bad as it could be'). The ATCs also provided information regarding events, pauses, work position and shift.

D. ECG data processing and analysis

Physiological stress was quantified based on diverse measures of HRV (Table 1). These measures are in accordance with the recommendations by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [14] for stress assessment. Decreased values of AVNN, RMSSD, pNN50 and increased values of LF/HF are indicative of stress [5]. Table 1 sums up these HRV parameters and their trend under stress and also includes self-reports used for stress analysis.

TABLE 1. Metrics used and their trend under stress

Metrics used and their purpose			
Domain	***Parameter***	***Description***	***Features trend under stress***
Linear HRV	AVNN	Average of NN intervals (ms)	↓
	RMSSD	Root mean square of differences of successive NN intervals (ms)	↓
	pNN50	NN variations above 50 ms (%)	↓
	LF/HF	Describes the ratio of LF and HF frequency power bands.	↑
Self-reports	PSS	Chronic stress	↑
	Stress symptoms questionnaire	Cognitive and physical stress symptoms	↑
	VAS	Stress and fatigue state assessment	↑

In order to extract heartbeat data from the ECG recordings, we used the Biodevices, S.A. ECG analyzer, which uses a validated algorithm based on Pan and Tompkins method [16] that detects each heartbeat in the ECG recording, locating the 'R' points of the ECG waveform. Using this analyzer, the RR intervals were extracted. A verification process was then implemented [18] to verify if all the RR intervals were physiologically valid. Valid RR intervals are described as normal-to-normal (NN) intervals. HRV metrics were computed with a proprietary software using 5 min' windows, without overlapping and excluding participant's movement data. However, since the total number of 5-min ECG blocks among all subjects was not balanced between assessment moments, a minimum number of 5-min ECG blocks was chosen randomly from the raw samples distribution of HRV shift analysis. Hence, 3 blocks of 5 min per person were chosen for shift *vs* days off condition and events vs non-events analysis, and 6 blocks of 5 mint per person for the analysis of pauses. This allowed to perform statistical comparisons considering a balanced sample number per condition.

D. Statistical analysis

Data were statistical analyzed using IBM SPSS AMOS (v.26) software. Taking into account the little number of population samples, some parameters failed in the normality test, so non-parametric statistical tests were used [15]. Wilcoxon Signed Test and Kruskal-Wallis Test were the nonparametric alternatives used to compare means between study time points. Paired- samples T-Test was used as Post-hoc pairwise comparisons to determine the exact differences between the time pairs.

III. RESULTS AND DISCUSSION

Our first goal was to *obtain an indication of ATCs perceived chronic stress levels*. Chronic stress levels were inferred based on the results from the PSS. The total average was 24 (± 9,65), which can be considered a low level [3]. Additionally, considering the impact of stress on physiology, the following results are related with physiological variations in subjects using ECG-derived measures.

Regarding *goal 2 – understand stress variations during shifts and days off,* Wilcoxon results (z=-2,662, p<0.05, with a medium effect size (r=0.42)) showed significant differences on stress symptoms from the beginning to the end of the shift. Participants reported an increase of stress symptoms from the beginning (*Md*=1) to the end of shift (*Md*=2). When comparing physiological data between shifts and days off, significant differences were also found for AVNN (z=-2,331, p<0.05, with a medium effect size (r=35)) and LF/HF (z=-2,839, p<0.05, with a medium effect size (r=0.42)), showing more physiological arousal during shifts when comparing to days off (Table 2).

TABLE 2. Stress metrics variation during shifts and days off

	Study moments			
HRV		*Shift*	→	*Day off*
	AVNN*(ms)	733,87 ± 77,26	↑	762,91 ± 56,41
	RMSSD (ms)	24,06 ± 6,68	↓	23,38 ± 9,54
	pNN50 (%)	5,84 ± 4,82	↑	6,04 ± 5,96
	LF/HF*	4,6 ± 2,35	↓	3,29 ± 1,67
Self-reports	Stress symptoms (1 – 5)	*Beginning* *End*	→	*Beginning* *End*
		1,49± 0,43 2,68±0,41	↓	1,55 ± 0,47 1,75 ± 0,54

*Wilcoxon test, p<0.05

Lower values of AVNN during shifts suggest a cardiac sympatho-excitation, characteristic in stress situations [18]. This response suggests a higher degree of activation of the cardiovascular system to compensate the body physiological responsiveness to stress. Accordingly, a higher LF/HF ratio during shifts reflects the domination of the sympathetic system over the parasympathetic one, also typical of stress responses [5]. Regarding *goal 3 – comparison of stress levels during reported ATC events and non-events moments*, no significant statistical results were found for psychophysiological stress data during events and non-events during shifts. The common reported events were related to: intense air traffic situations (23); aircrafts conflicting information (3); airspace sectorization problems (3). Finally, our *last goal was to compare psychophysiological stress levels before (pre-pause), during and after working pauses (post-pause).* A significant decrease on perceived stress levels was found after pauses, using VAS (Wilcoxon test; z=-4.585, p<0.005, with a large effect size, r=.60). The median score decreased on perceived stress from the pre-pause (*Md*=2) to the pots-pause period (*Md*=1). Regarding physiological ECG data, significant statistical differences were found for AVNN, $\chi2$ (2, n=270) = 15,302, p<0.001 and for LF/HF, $\chi2$ (2, n=270) =25,857, p<0.001. Results showed a higher physiological activation during the pre-pause period (lowest value of AVNN and highest of LF/HF).

TABLE 3. Stress metrics obtained during study moments

		Study moments				
		Pre_pause	→	*Pause*	→	*Post-pause*
HRV	AVNN**	725,21 ± 45,96	↑	758,41 ±93,23	↓	736,85 ± 97
	RMSSD	21,45 ± 6,66	↑	22,16 ± 7,64	↑	22,29 ± 7,8
	pNN50	3,973 ± 4,06	↑	4,23 ± 4,72	↑	4,77 ± 4,07
	LF/HF**	6,03 ± 3,02	↓	4,92 ± 3,18	↑	5,6 ± 2,67
Self-reports	VAS	1,94 ± 1,56		↓		1,27 ± 1,18

**Kruskall-Wallis test; p<0.001

In order to determine the exact differences between time pairs, particularly for pre-pause and post-pause period, we conducted post-hoc pairwise comparisons and significant differences were found for all HRV metrics for these two periods ($p<0.05$). These results along with self-reported data strongly suggest that working pauses positively work as a recovery period. Results also reinforced the discriminatory power of AVNN and LF/HF for short-term stress classification using HRV measurements. Currently, we are working on the development of a robust stress index algorithm, using results obtained from previous studies [20].

IV. CONCLUSION

The current study used a novel BWP to assessment stress among ATCs. Findings provide an insight on psychophysiological stress levels of ATCs when working under real world conditions and confirm the acceptability, feasibility and research potential of the multimethod used., by identifying stress perceptions and physiological body variations along different moments. Despite this study limitations, particularly the reduced sample size, we believe this study shows the method could be a good starting point for larger studies with ATCs, or other professional groups, with the appropriate changes, and also including other variables such as fatigue and sleep analysis. Occupational health settings may benefit from the use of these methods and this information could be helpful for: a) researchers in the development of quantified Occupational health technology, like the design of on-line platforms and devices to integrate stress information; b) individuals, by increasing awareness on their stress levels using reliable biomarkers; c) organizations, by providing more accurate information regarding employer's health status in real time, increasing the performance of the production system, improving organizational policies in occupational health area and promoting team management, e.g, with the inclusion of routinely health and stress analysis. These findings will help on the design of stress management programs and prevention actions in order to avoid the negative effects of stress and consequently reduce costs for the aviation sector organizations and national healthcare systems.

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