

---

Citation:

Rodrigues, S and Kaiseler, M and Pimentel, G and Rodrigues, J and Aguiar, A and Queirós, C and Cunha, JPS (2018) Ambulatory assessment of psychophysiological stress among police officers: A proof-of-concept study. *Occupational Health Science*, 2 (2). pp. 215-231. ISSN 2367-0134 DOI: <https://doi.org/10.1007/s41542-017-0008-y>

Link to Leeds Beckett Repository record:

<https://eprints.leedsbeckett.ac.uk/id/eprint/4339/>

Document Version:

Article (Accepted Version)

---

This is a pre-print of an article published in *Occupational Health Science*. The final authenticated version is available online at: <https://doi.org/10.1007/s41542-017-0008-y>

The aim of the Leeds Beckett Repository is to provide open access to our research, as required by funder policies and permitted by publishers and copyright law.

The Leeds Beckett repository holds a wide range of publications, each of which has been checked for copyright and the relevant embargo period has been applied by the Research Services team.

We operate on a standard take-down policy. If you are the author or publisher of an output and you would like it removed from the repository, please [contact us](#) and we will investigate on a case-by-case basis.

Each thesis in the repository has been cleared where necessary by the author for third party copyright. If you would like a thesis to be removed from the repository or believe there is an issue with copyright, please contact us on [openaccess@leedsbeckett.ac.uk](mailto:openaccess@leedsbeckett.ac.uk) and we will investigate on a case-by-case basis.

**Ambulatory assessment of psychophysiological stress among police officers: A proof-of-concept study**

<sup>1</sup> Rodrigues, S., <sup>2</sup> Kaiseler, M., <sup>3</sup> Pimentel, G., <sup>4</sup> Rodrigues, J., <sup>5</sup> Aguiar, A., <sup>6</sup> Queirós, C., & <sup>7</sup> Cunha, J.P.S.

<sup>1,6</sup> Faculty of Psychology and Educational Sciences, University of Porto, Portugal.

<sup>2</sup> Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, UK.

<sup>1,3,7</sup> Center for Biomedical Engineering Research (C-BER) of INESC TEC Porto, and Faculty of Engineering, University of Porto, Portugal.

<sup>4,5</sup> Institute of Telecommunications, Department of Electronic Engineering and Computers, Faculty of Engineering, University of Porto, Portugal.

**Author Note:**

Correspondence should be sent to: Susana Rodrigues. INESC TEC - INESC Technology and Science and FEUP - Faculty of Engineering, University of Porto, Portugal. Rua Dr. Roberto Frias s/n Edifício 1, 4200-465 Porto Portugal Telephone: 22 209 4000 Email: susanarodrigues\_@hotmail.com.

Ambulatory assessment of psychophysiological stress among police officers: A proof-of-concept study

### **Abstract**

Occupational stress has been widely recognized as a global challenge and has received increased attention by the academic community. Ambulatory Assessment methodologies, combining psychophysiological measures of stress, offer a promising avenue for future prevention and/or rehabilitation stress research. Considering that policing is well known for being a particularly stressful occupation, Emergency Responders Officers (EROs) stress levels were investigated. Particularly, this study analyzed: (i) physiological stress data obtained during shifts and compared these data with baseline levels (days off), as well as (ii) with normative values for healthy populations; (iii) stress symptoms differences from beginning to end of shift; (iv) stress events and events intensity and (v) the acceptability and feasibility of this proof-of-concept study in a highly stressful occupation. A Geo-location event system was used to help retrospective accounts of psychological stress, combined with electrocardiogram (ECG) data and mobile self-reports, that include stress symptoms, event types and event intensity. Results suggest that EROs experience high levels of stress (both on-duty and off duty) when compared to healthy populations. Stress symptoms increase from the beginning to end of the shift. However, the mean events intensity was very low. It can be concluded that stress may not always be diagnosed when using merely self-reports. These findings highlight the importance of combining both self-report and physiological stress measures in occupational health contexts. Finally, results confirm the acceptability and feasibility of the multi-method used. Key implications for policy makers and applied practitioners in the area of occupational health and future research directions are discussed.

43    *Keywords:* occupational health; ambulatory assessment; geo-location; stress; psychophysiology;  
44    Emergency Response Officers.

45

46

47

48

49

50

51

52

53

54

55

56

57

58

59

60

61

62

63

64

65

## 66   **Introduction**

67           The understanding of occupational stress, known as a particular form of stress that  
68 involves work (Dewe, O'Driscoll, & Cooper, 2010), should be of great concern, regarding the  
69 risks involved not only for the employee and organization, but also for national economies  
70 (Cartwright & Cooper, 1997). The experience of stress at work is one of the major problems  
71 affecting health and safety in Europe (Nakao, 2010). Accordingly, approximately one in four  
72 employees suffer from stress-related conditions, and empirical evidence suggests that between  
73 50% and 60% of work absence days are due to stress associated problems (Maracine, 2010).

74           Stress can be defined as a pattern of negative physiological states and psychological  
75 responses that occur in situations that are appraised as taxing or exceeding individual's resources  
76 (Lazarus & Folkman, 1984). Stress is physiologically characterized by an onset of body  
77 alterations. Cannon (1914), described this as the "fight-or-flight" response. When a threat is  
78 perceived, the autonomic nervous system (ANS) is triggered, the parasympathetic nervous  
79 system, that controls homeostasis and the body at rest, is suppressed and the sympathetic nervous  
80 system, that controls the body's responses to a perceived threat is activated. Consequently, the  
81 secretion of stress-related hormones leads to several physiological responses, including the  
82 vasoconstriction of blood vessels, increased blood pressure and breathing rate, increased muscle  
83 tension and heart rate (HR) and a decrease in heart rate variability (HRV). Once the threat is no  
84 longer present, a sympathovagal balance is reestablished through homeostasis between the  
85 parasympathetic and sympathetic system (Taelman, Vandeput, Spaepen, & Van Huffel, 2008).  
86 These mechanisms describe the body's response to a stressful stimulus, by rapidly mobilizing  
87 energy and providing an adaptive response.

Although isolated acute stress responses do not inevitably cause chronic disease, health risks are increased when stressors, or the stress response is frequent and/or persists over long stages (Smyth, Zawadzki, & Gerin, 2013). Particularly, the continuous activation of the stress systems can lead to serious modifications on the neuro-autonomic and endocrinal balance, creating higher levels of psychological (i.e., depression, anxiety) and physiological problems (i.e., hypertension, coronary heart disease, gastrointestinal malfunctions, metabolic syndrome) (Fenici, Brisinda, & Sorbo, 2011).

Previous studies in occupational health have used a variety of biological markers of stress, such as cortisol (e.g., Collip et al., 2011), HR, HRV (e.g., Dockray et al., 2010), and blood pressure (BP) (e.g., Ewart & Johnson, 2004). However, there seems to be agreement among the academic community that HRV is the most feasible and reliable way to assess stress physiological responses (Task Force, 1996; Healey & Picard, 2005). HRV is a noninvasive measure for cardiovascular monitoring and offers the opportunity to simultaneously investigate associations between psychological processes and physiological reactions (Orsila et al., 2008). The HRV refers to cardiac rate alterations, particularly, the complex variations of both instantaneous heart rate and the series of inter-times between consecutive peaks of the R-wave of the electrocardiogram (ECG) (RR intervals). This variation is controlled by the ANS, which through the parasympathetic and the sympathetic branches, is responsible for adjusting the HR in response to external or internal physical or emotional stimulus (e.g., stress). When HRV is lower, it suggests that control mechanisms are not functioning correctly (van Ravenswaaij-Arts, Kollée, Hopman, Stoelinga, & van Geijn, 1993). Low HRV is of specific interest to psychologists, since it has been linked with poorer self-regulatory mechanisms, due to the connection of the vagal nerve (a key component that determines HRV) to the same neural network involved in emotional

regulation (Appelhans & Lueken, 2006; Koval, Ogrinz, Kuppens, Van den Bergh, Tuerlinckx, & Sutterlin, 2013).

Despite advances in stress assessment research in the area of occupational health, there are still several challenges to address. First, traditional stress assessment designs are often retrospective and cross-sectional in nature, using mainly self-report measures. Consequently, data collected may be negatively influenced by memory biases or distortions associated with time delays, challenging the validity and reliability of the reports (Segerstrom & O'Connor, 2012). Second, laboratory designs are the common used solution to address the limitations presented above, since they avoid retrospective limitations and can add the rigor of an experimental design (Smith & Stone, 2003). However, laboratory experiments fail to represent real-world settings, due to the inherent artificial conditions. Finally, there seems to be a lack of reliable physiological methods that can be used to assess stress responses in applied settings, particularly among emergency professions such as policing (Hickman, Fricas, Strom, & Pope, 2011; Kusserow, Amft, & Troster, 2013).

Policing is well known for being a stressful occupation (Strahler & Ziegert, 2015), therefore the monitoring of stress among police officers working in real world scenarios seems to be a key research priority. Despite this need, such an investigation presents several challenges since stress responses can vary across individuals, situations, stressor typologies and can occur at random times, varying in duration and intensity (Kusserow et al., 2013). Although much work has been conducted to better understand police stress, most of these studies relied mainly on self-report measures. An exception is a study by Hickman et al. (2011) that aimed to investigate police stress using direct real-time and spacially anchored measurements of an officer's response to stressors and the sample consisted of one police officer. Although the study demonstrated that

continuous measurement of police officers cardiac response during a shift is possible, results were limited by the lack of self-report stress data considered. Hence, raising questions on whether observed HR increases were due to psychological stress or merely increases in physical activity.

In order to overcome previous limitations in this area and considering that stress is a complex topic, Rodrigues et al. (2015) argued that work stress investigations should be multidisciplinary in nature and should employ multi-methods research approaches. In other words, studies should include accurate and reliable measurements of stress supported by both psychological and physiological data, preferably synchronized, and contain control technologies for possible confounder variables biasing physiological data. Accordingly, Trull and Ebner-Priemer (2013) proposed Ambulatory Assessment as a new research tool that covers a wide range of assessment methods combining self-report, observational, and physiological/behavioral measurements for data collection during real life settings.

The current study used a multi-method ambulatory approach to assess EROs' stress levels. Particularly, this study analyzed: physiological stress data obtained during shifts and compared these data with (i) baseline levels (days off), (ii) normative values for healthy populations, (iii) stress symptoms differences from beginning to end of shift, (iv) stress events and events intensity ratings and (v) the acceptability and feasibility of this multi-method approach within this population. This method synchronizes self-reports and physiological stress data collected in real-time during an entire workday. These data were then compared to a non-work day and all physiological data were then compared with normative values. The method included a geo-located event system with ECG data, using user-friendly, non-intrusive mobile and wearable technology. The geo-location system allowed to monitor stress information in a



smartphone, using Global Positioning System (GPS) and contemplated the exact location where the event occurred. The geo-located data were used to facilitate participant's memory retrieval of stressful events (Rodrigues, Kaiseler, Queirós & Basto-Pereira, 2017). The amount of time participants spent with the equipment, level of compliance, problems/interference reported and their engagement/satisfaction were investigated to test the acceptability and feasibility of this approach.

## **Method**

### **Participants**

Six male EROs from a national police force in the second largest city of Portugal were recruited from a larger study ( $N=14$ ) assessing stress and coping (Rodrigues et al., 2017). The EROs mean age was 34.57 years ( $SD=4.32$ ) Participants performed emergency police duties, since they were part of a rapid intervention team that was on-call 24/7 to intervene in critical situations. All participants had over five years of experience in policing. The exclusion criteria for the study were participants having a history of cardiovascular disease and/or taking prescription drugs known to affect cardiovascular function. Participants were instructed to perform no changes in their daily routine, such as sport activities, caffeine, nicotine and food consumption. The study was approved by the University of Porto ethics committee and the Portuguese National Police Force Board. Participants were instructed about the voluntary nature of participation and the confidentiality of their responses.

### **Design**

A presentation session was organized to explain the aim and protocol of the study, including a psychoeducational component regarding the stress topic. The purpose of this component was to help participants identify stressful events or symptoms. The study instructions

were explained to participants face-to-face by the first author, including a detailed demonstration of procedures. Participants were instructed about the voluntary nature of participation and the confidentiality of their responses.

Data was collected during one workday (approximately 8 hours) and one non-work day. For non-working days, participants were required to only use an ECG monitor - VitalJacket® to collect ECG baseline data. During these days, participants were instructed to rest as much as possible and avoid participating in rigorous physical activities. After data collection on non-working days, participants were asked about any stressful events experienced; however, nothing was reported. For the workdays, participants were requested to carry the VitalJacket® and a smartphone with a software application (app). EROs provided information regarding stress symptoms, event types and event intensity. A diagram illustrating the study protocol during shifts is shown in Figure 1.

FIGURE 1 ABOUT HERE

## **Materials and measures**

### **Physiological data**

For physiological data collection, a wearable t-shirt incorporating an ECG monitor - VitalJacket® was used (Cunha, 2010; 2012) (see Figure 2). The VitalJacket® is a wearable bio-monitoring device that provides real-time ECG at a sampling rate of 500 Hz, through one lead and a three axis Accelerometer (ACC). The ACC is an inertial sensor that measures body's acceleration in 3-axis (x,y,z). Particularly, when a body changes its position the ACC is able to measure this change, as well as the intensity of the movement. In terms of participants' activity, the ACC gives a movement/activity intensity indication. In terms of mathematics, a simple quadratic mean (quadratic mean= $\sqrt{(acc_x^2 + acc_y^2 + acc_z^2)/3}$ ) is computed using all three axis

( $acc_x$ ,  $acc_y$ ,  $acc_z$ ), giving a global activity indicator, independent of the direction of movement.

This sensor is in the VitalJacket® system and records the participant movement intensity while monitoring the ECG. Participants did not report any problems regarding the use of the equipment or any interference it may have had with their daily activities.

## FIGURE 2 ABOUT HERE

Physiological stress was assessed based on different components of HRV. These measures followed the guidelines presented by the Task Force (1996), that are feasible for stress assessment:

- AVNN - Average of (normal-to-normal) NN intervals that indicate the number of heart cycles observed per temporal interval.
- Root Mean Square of Differences between successive NN intervals (RMSSD) - This value is obtained by first calculating each successive time difference between heartbeats in milliseconds. Then, each of the values is squared and the result is averaged before the square root of the total is obtained. The RMSSD reflects the beat-to-beat variance in heart rate and is the primary time domain measure used to estimate the vagally-mediated changes reflected in HRV (Shaffer, McCraty, & Zerr, 2014).
- pNN50 - the percentage of the number of times per hour in which the change in consecutive normal sinus (NN) intervals exceeds 50 milliseconds; this measure facilitates assessment of parasympathetic (vagal) activity from 24 hour ECG recordings (Ewing, Neilson, & Travis, 1984).
- Low Frequency (LF) - is a band of power spectrum ranging between 0.04 and 0.15 Hz. and it is used as an accurate reflection of sympathetic activity (Reyes del Paso, Langewitz, Mulder, van Roon, & Duschek, 2013).

- High Frequency (HF) - is a band of power spectrum ranging between 0.15 and 0.4 Hz. This represents an index of cardiac parasympathetic tone (Reyes del Paso et al., 2013).
- LF/HF Ratio - this is the ratio between the power of Low Frequency and High Frequency bands. This measure indicates overall balance between sympathetic and parasympathetic systems. Higher values reflect domination of the sympathetic system, while lower ones suggest domination of the parasympathetic system.

Decreased values of AVNN, RMSSD and pNN50 are indicative of stress. Additionally, increased values of LF and LF/HF are also indicators of stress (Castaldo et al., 2015). Table 1 describes these HRV parameters and their trend under stress.

TABLE 1 ABOUT HERE

### **Self-report data**

Demographic and medical surveys were used in order to assess participants' current health status and assure that the inclusion criteria were fulfilled. A smartphone with a software application (app), based on the SenseMyCity crowd sensing platform (Rodrigues, Aguiar, & Barros, 2014) was used. This platform consists of an app using smartphones, that includes a back office and a front office and collects real time data from embedded sensors (e.g., GPS, accelerometer, among others). This app allows participants to describe events, and rate stress levels and symptoms (see Figure 3).

FIGURE 3 ABOUT HERE

### **Stress symptoms**

In order to understand the cognitive and physical symptoms of stress, a questionnaire was used. This instrument included four questions related with physical ("1- Muscular tension"; "2- Eye fatigue or heavy head"; "3- Nausea, abdominal discomfort and stomach pain"; "4- Difficulty

in maintaining the body straight”) and cognitive aspects (“5- Concentration problems”; “6- Difficulty in reasoning, thinking or answering”; “7- Affliction or nervousness”; “8- Difficulty in maintaining control”). Participants were asked to rate each item on a Likert-type scale ranging from 0 – “*Not felt at all*” to 4- “*Extremely felt*”. These questions were fulfilled in the software app (based on Cohen & Williamson, 1988) at the beginning and end of the day, aiming to evaluate whether there were alterations in stress symptoms experienced in these two moments.

### **Event type**

Type of events experienced during shifts were assessed by selecting an option from a stressor checklist (Drug traffic; Public disorder; Neighborhood intervention; Vehicles chase; Inadequate resources; Other). For the purpose of this paper, stressful situations were defined as “a situation that taxes or exceeds one’s personal resources or threatens the person wellbeing has the potential to cause stress”(Lazarus & Folkman, 1984; p.19). The stressor checklist was developed following pilot work (see Rodrigues, Kaiseler, Queirós, & Basto-Pereira, 2017). This pilot work included a study where 14 ERO’s completed daily diaries over 11 working days. Each diary entry included an open-ended question, where participants reported the most common stressors, these answers formed the stressor checklist for this study.

### **Event intensity**

Stress intensity levels were assessed for each event using a 5-point Likert-type scale ranging from 1- “*Not at all stressful*” to 5 - “*Extremely stressful*”. (Kaiseler, Queirós, Passos, & Sousa, 2014). Single-item measures were used since they present several benefits, for a detailed review of these please see Fisher, Matthews, and Gibbons (2016).

### **Geo-location data**

All data gathered with the smartphone were exported to a web server to be processed. The processed ECG data, together with the GPS information and the Google Earth platform information were used to display the location history for the full shift for each participant (see Figure 4). Each reported event and other potential stressful events were detected through an automated algorithm (following Rodrigues, Kaiseler, Aguiar, et al., 2015) and were imported into Google map. These events were then presented to participants at the end-of-shift interview, aiming to facilitate memory recall and help on a more accurate description of stressful events as described in Rodrigues et al. (2015) (see details in Figure 4).

FIGURE 4 ABOUT HERE

## **Data analysis**

### **Physiological data analysis**

A software including an algorithm following Pan Tompkins's work (Pan & Tompkins, 1985) was used to analyze ECG data (Biodevices S.A). All HRV metrics (AVNN, RMSSD, pNN50, LF, LF/HF) were computed using 5 minutes' windows, without overlapping and excluding participant's movement data. HRV metrics were compared during shifts and days off and were also compared to healthy individual's normative values following Voss, Schroeder, Heitmann, Peters, and Siegfried (2015) study. This study included the largest population of healthy individuals ( $N=1,906$ ) and aimed to analyze age and gender related HRV differences.

### **Self-report data analysis**

Self-reported data collected using the smartphone and end-of-shift interviews were subject to a quantitative between-person variation analysis, centered on an event-based approach. Quantitative data from stress symptoms questionnaires were analyzed using a non-parametric hypothesis test – the Wilcoxon Signed Test - conducted using IBM SPSS AMOS (v.22) software.

This test was used to compare participants' stress symptoms mean scores at the beginning and end of shifts. A value of  $p < .05$  (two tailed) was considered statistically significant. The internal consistency for the 8 questions of the stress symptoms questionnaire was calculated using Cronbach's alphas. This value provides a coefficient of reliability, and is used as a measure of internal consistency for participants' answers. As recommended these values should be above 0.70 (Pallant, 2011). In the current study, the Cronbach's alphas were 0.94. Quantitative event intensity levels were calculated considering the mean intensity of each event.

### **Geo-location event-system analysis**

The geo-located event system analyzed physiological data and monitored potential stressful events based on the cardiac signal retrieved from the VitalJacket®. The ECG data were divided in blocks of 100 seconds and processed using the HRV Toolkit from Physionet (Goldberger et al., 2000). This is a rigorously validated package of open source software for HRV analysis, including visualization of NN interval time series and automated outlier removal. These HRV statistics are well accepted among scholars (e.g., Castaldo et al., 2015). The system extracted HRV metrics, analyzed them and selected the places (using GPS) where a potentially stressful event occurred. These events were selected from all the moments the EROs reported an event on the app, combined with the blocks having the highest algorithms of HRV's LF power, but separated by at least 5 minutes from each other.

## **Results**

### **Physiological data**

A total of 47h of annotated ECG recordings during shifts and 30h of data during days off were collected and analyzed, resulting in a total of 77h of high medical grade ECG signal.

Results from AVNN, RMSSD and pNN50 mean values were lower than normative values when participants were on duty. The mean LF/HF ratio was higher than normative values for both shifts and days off (Figure 5). Additionally, two examples of this ECG signal analysis during specific events (“Driving fast”; “Gun situations” – Table 2) provided by the EROs also indicate the presence of physiological stress, considering the high values of LF/HF and low values of AVNN and pNN50 (Figure 6 a) and b).

FIGURE 5 ABOUT HERE

FIGURE 6 ABOUT HERE

TABLE 2 ABOUT HERE

## **Self-report data**

### **Stress symptoms (beginning vs end of shift)**

Regarding stress symptoms, results from the Wilcoxon Signed Test showed no statistically significant change for physical and cognitive stress between the beginning and end of shift symptoms ( $Z = -1.60$ ,  $p > .05$  and  $Z = .37$ ,  $p > .05$ , respectively). However, the overall mean score of stress symptoms was higher at the end of the shift ( $M = 1.73$ ;  $SD = .85$ ) compared with the beginning of shift ( $M = 1.50$ ;  $SD = .51$ )

### **Event intensity**

Stress events reported and respective stress intensity levels are presented in Table 2. Regarding quantitative stress intensity measures, the stress intensity scores ranged from 0 to 5, and the overall mean was 2.1 ( $SD = .99$ ). “Suspect escape” was the most intense stress event reported ( $M = 4.0$ ), followed by “Public disorder ( $M = 3.0$ ) and “Gun situation” ( $M = 3.0$ ).

## **Geo-located event system**



In total nine events were reported by all EROs using the geo-located system (Table 2). The most cited event type was “neighborhood interventions” (cited three times), followed by “Public disorder” situations (cited two times).

### **System acceptability and feasibility**

All participants (100%) carried out the study “kit” during both a shift and a day off and did not report any problems regarding usage or interference with daily activities. Regarding the use of the software app, the majority of participants (five in six; 83%) forgot to use it after a stressful event. An exception was only one stressful event that was reported on duty by one officer. In what concerns to the use of the software app to assess stress symptoms at the beginning and end of the shift, out of the six, five EROs (83%) completed the questionnaires on both occasions.

### **Discussion**

The current study used an ambulatory multi-method approach to assess psychophysiological stress responses in occupational health field and aimed to test the acceptability and feasibility of this method in a sample of EROs. Particularly, this study investigated: (i) physiological data obtained during shifts and compared these data with baseline levels (days off), as well as (ii) with normative values for healthy populations; (iii) stress symptoms differences from beginning to end of shift; (iv) stress events and events intensity and (v) the acceptability and feasibility of this proof-of-concept study among a highly stressful profession.

Findings provide an insight on psychophysiological stress levels of EROs when working under real world conditions and confirm the acceptability, feasibility and research potential of the method to be used in similar emergency occupational settings.

The physiological analysis suggested that EROs experienced high levels of physiological stress, when compared to baseline levels (days off) and when compared to healthy individuals based on the study conducted by Voss et al. (2015). With the exception of Voss and colleagues' paper, it is important to highlight the inexistence of studies including normative values of HRV in large healthy populations. Furthermore, to the best of our knowledge, this is the first study to provide police officers' HRV measures while working in real world conditions, highlighting the original contribution of the findings to this body of knowledge. The physiological analyses indicate stress based on the decreased values of AVNN, RMSSD and pNN50 that reflected a depressed HRV during stress (Castaldo et al., 2015). Finally, the LF/HF ratio was higher than normative values, whether the participants were on-duty or off-duty. Higher values reflect domination of the sympathetic system, while lower ones refer a higher activity from the parasympathetic system, which is compatible with stress responses (Kaur, Bhalla, Bajaj, Sanya, & Babbar, 2013).

Regarding EROs psychological stress symptoms at the beginning compared to end of the shift, findings suggest that there was a minor increase in symptoms. However, this was not statistically significant, probably due to the reduced sample size. The observed tendency supports previous work conducted among Portuguese police officers (e.g., Gomes et al., 2012) showing that physical and cognitive stress symptoms increase during the working day, probably due to experience of stress events. These findings suggest that this population may be experiencing potential cumulative stress effects along the days. Future longitudinal studies are required to confirm this assumption. Additionally, despite the fact that findings suggest the experience of higher stress symptoms at the end of the shift, five out of six EROs participating in the current study did not rate any experienced events as stressful. These findings may suggest that EROs

may not be aware of their stress and its impact on their health and may therefore be unlikely to ask for help.

Accordingly, the results of the ECG analysis (using AVNN, pNN50 and LF/HF metrics) performed during specific events showed that, particularly for “Gun situations”, physiological stress was evident in the ECG signal, but this event was not rated as stressful. It is crucial to highlight the importance of the current multi-method approach to understand these compiling findings. Particularly, if only self-report measures were used, one could potentially reach the premature conclusion that EROs do not experience stress events. Hence, combining psychophysiological measures of stress seems to be key to fully understand these professional’s occupational health while working under real world conditions.

A possible explanation for the fact that EROs do not rate events as stressful could be due to the fact that those events are regularly experienced by them during their shifts, therefore they do not perceive them as stressful, but rather as a routine part of their daily work. An alternative explanation for these findings could be related to the police culture. As stated by Turvey (1995) an officer is expected, by his culture to endure, not to talk about problems or concerns with others. Officers are expected to maintain a surface immunity to their own humanness. When a police officer expresses psychosocial stress, this could be viewed as a weakness, therefore they do normally avoid reporting it (Anshel, 2000). Further qualitative research designs are required to fully understand EROs appraisal of stress events in real world.

These findings should be useful for practitioners working with police officers. It is recommended that police practitioners work collaboratively with officers to combat the stigma of mental health problems and treatment, by normalizing help-seeking behavior (Papazoglou & Andersen, 2014). Additionally, future interventions for this population could include the

development of peer-to-peer programs, since previous research has shown that officers seem reluctant to look for clinicians (Manzella & Papazoglou, 2014; Waters & Ursury, 2007).

Regarding the acceptability of this study, this was assessed considering the use of the equipment and the engagement with the methodology. All officers carried the study “kit” all day, without reporting any disturbance with the equipment, demonstrating the high acceptability and feasibility of this method. In regards to the use of the geo-located system, in agreement with Rodrigues et al. (2015) findings among bus drivers, this method seems to facilitate memory retrieval among EROs when identifying stressful events. Other possible future advantage in GPS location tagging could be the chance to have this data available in real time allowing for police commanders to have a better control of their teams and it would be easier to identify stressful hotspots (e.g., dangerous neighborhoods, roads). Additionally, from an implementation perspective this system may be a tool to provide citywide “stress maps”, spotting areas in need for an emergency response or a local authority intervention. It is recommended that future studies should test the functionality of the system with different professionals working in urban mobile environments.

The current ambulatory multi method approach seems to be a promising tool to support first responders’ occupational health diagnostic and interventions while also informing management decisions in real time. The current method was key to understand occupational stress among EROs and findings provide key practical and methodological implications. Considering the contemporary increased demands on security, officers’ stress monitoring during real world events should be at the forefront of occupational research priorities. Furthermore, our findings suggest that police practitioners should implement healthy routines (e.g., healthy eating

habits, exercise and lifestyle), monthly medical and physical monitoring, and group sessions for stress symptoms detection, aiming to help officers cope more efficiently with daily stress.

The current study is not without limitations. First, is the low level of compliance for specific kinds of data, such as the little use of the software app following events. This could be due to the fact that EROs do not perceive events as stressful. Alternatively, they could be too involved in daily events, restricting their capacity for study compliance. A possible solution to overcome this challenge is to have an audible/vibrating alert system in the smartphone, capable of detecting changes in HRV parameters after a stressful event, and warning EROs to fulfill a quick stress survey. Alternatively, participants could report events only at the end of the shift using the geo-located event system. Second, the small sample size, and short time duration of data collection should also be acknowledged as limitations. Finally, it is also important to acknowledge that this type of methodology is resource intensive in terms of software, technology and expertise (i.e., psychology, biomedical and informatics).

Despite these limitations, we believe that our 77h of geo-located data is one of the largest datasets obtained with police officers, and our results point to some promising avenues for future research and practice that can be used with larger samples and different occupational groups. Hence, findings from the current study extend the body of knowledge of occupational stress assessment and provide a feasible and accurate methodology allowing a holistic approach to stress assessment among highly stressful professions working under real world conditions.

Author note: On behalf of all authors, the corresponding author states that there is no conflict of interest.

## References

- Anshel, M. H. (2000). A conceptual model and implications for coping with stressful events in police work. *Criminal Justice Behavior*, 27(3), 375-400.
- Appelhans, B.M., & Luecken, L.J. (2006). Heart rate variability as an index of regulated emotional responding. *Review of General Psychology*, 10, 229–240. doi: 10.1037/1089-2680.10.3.229
- Biodevices, S.A. (n.d.). Certifications. Retrieved from [http://www.vitaljacket.com/?page\\_id=144](http://www.vitaljacket.com/?page_id=144)
- Cannon, W. B. (1914). The emergency function of the adrenal medulla in pain and the major emotions. *American Journal of Physiology*, 33, 356-372.
- Cartwright, S. & Cooper, C. L. (1997). *Managing workplace stress*. Thousand Oaks, CA: Sage Publications.
- Castaldo, R., Melillo, P., Bracale, U., Caserta, M., Triassi, M., & Pecchia, L. (2015). Acute mental stress assessment via short term HRV analysis in healthy adults: A systematic review with meta-analysis. *Biomedical Signal Processing and Control*, 18, 370-377. doi: <http://dx.doi.org/10.1016/j.bspc.2015.02.012>
- Cohen, S., & Williamson, G. M. (1988). Perceived stress in a probability sample of the United States. In S. Spacapan & S. Oskamp (Eds.), *The social psychology of health* (pp. 31-67). Newbury Park, CA: Sage.
- Collip, D., Nicolson, N. A., Lardinois, M., Lataster, T., van Os, J., & MyinGermeys, I. (2011). Daily cortisol, stress reactivity and psychotic experiences in individuals at above average genetic risk for psychosis. *Psychological Medicine*, 41, 2305-2315. doi:10.1017/S0033291711000602

- 475 Cunha, J.P.S., Cunha, B., Pereira, A.S., Xavier, W., Ferreira, N. & Meireles, L.A. (2010). Vital  
 476 Jacket: A wearable wireless vital signs monitor for patients' mobility in Cardiology and  
 477 Sports. *4th International ICST Conference on Pervasive Computing Technologies for*  
 478 *Healthcare*. Munich, Germany.
- 479 Cunha, J.P.S. (2012). pHealth and Wearable Technologies: a permanent challenge. *Studies in*  
 480 *Health Technology and Informatics*. B. Blobel, P. Pharow and F. Sousa. Amsterdam, IOS  
 481 Press. 177, 185-195.
- 482 Dewe, P. J., O'Driscoll, M. P., & Cooper, C. L. (2010). *Coping with work stress – A review and*  
 483 *critique*. Chichester: Wiley-blackwell.
- 484 Dockray A., Grant, N., Stone, A. A., Kahneman, D., Wardle, J., & Steptoe, A. (2010) Comparison  
 485 of affect ratings obtained with ecological momentary assessment and the day  
 486 reconstruction method. *Social Indicators Research*, 99, 269–283. doi:10.1007/s11205-  
 487 010-9578-7
- 488 Ewart, C. K., & Jorgensen, R. S. (2004). Agonistic interpersonal striving: social cognitive  
 489 mechanism of cardiovascular risk in youth? *Health Psychology*, 23(1), 75–85.  
 490 doi:10.1037/0278-6133.23.1.75
- 491 Ewing, D. J., Neilson, J. M., Travis, P. (1984). New method for assessing cardiac  
 492 parasympathetic activity using 24 hour electrocardiograms. *British Heart Journal* 52,  
 493 396-402.
- 494 Fenici, R., Brisinda, D., & Sorbo, A. R. (2011). Methods for real-time assessment of  
 495 operational stress during realistic police tactical training. In J. Kitaeff (Ed.),  
 496 *Handbook of police psychology* (pp. 295-262). NY: Routledge Tayler & Francis  
 497 Group.

- 498 Fisher, G. G., Matthews, R. A., & Gibbons, A. M. (2016). Developing and investigating the use of  
 499 single-item measures in organizational research. *Journal of Occupational Health*  
 500 *Psychology*, 21(1), 3-23. doi:10.1037/a0039139
- 501 Goldberger, A. L., Amaral, L. A., Glass, L., Hausdorff, J. M., Ivanov, P. C., Mark, R. G., ...  
 502 Stanley, H. E. (2000). PhysioBank, physioToolkit, and physioNet: components of a new  
 503 research resource for complex physiologic signals. *Circulation*, 101, 215–220.
- 504 Gomes, P., Kaiseler, M., Queirós, C., Oliveira, M., Lopes, B., & Coimbra, M. (2012). Vital  
 505 Analysis: Annotating sensed physiological signals with the stress levels of  
 506 first responders in action. Paper presented at *Engineering in Medicine and Biology*  
 507 *Society Annual International Conference of the IEEE*, San Diego, USA.
- 508 Healey, J. A., & Picard, R. W. (2005). Detecting stress during real-world driving tasks using  
 509 physiological sensors. *IEEE Trans. on Intelligent Transportation Systems*, 6, 156–166,  
 510 2005. doi:10.1109/TITS.2005.848368
- 511 Hovsepian, K., al´Absi, M., Ertin, E., Kamarck, T., Nakajima, M. & Kumar, S. (2015). Stress:  
 512 Towards a gold standard for continuous stress assessment in the mobile environment.  
 513 *Proceedings of the 12th ACM international conference on Ubiquitous computing*, 493–  
 514 504. doi:10.1145/2750858.2807526.
- 515 Hickman, M. J., Fricas, J., Strom, K. J., & Pope, M. W. (2011). Mapping police stress. *Police*  
 516 *Quarterly*, 14(3), 227-250, doi:10.1177/1098611111413991
- 517 Kaiseler, M., Queirós, C., Passos, F., & Sousa, P. (2014). Stress appraisal, coping, and work  
 518 engagement among police recruits: an exploratory study. *Psychological Reports:*  
 519 *Employment Psychology & Marketing*, 114(2), 1-12. doi:10.2466/01.16.PR0.114k21w2



- 520 Kaur, S., Bhalla, P., Bajaj, S.K., Sanya, S., & Babbar, R. (2013). Effect of physical and mental  
 521 stress on heart rate variability in type-A and type-B personalities. *Indian Journal of*  
 522 *Applied Basic Medical Sciences*, 15(20), 1-13.
- 523 Koval, P., Ogrinz, B., Kuppens, P., Van den Bergh, O., Tuerlinckx, F., & Sutterlin, S.  
 524 (2013). Affective instability in daily life is predicted by resting heart rate variability.  
 525 *PLoS ONE*, 8(11), e81536. doi:10.1371/journal.pone.0081536
- 526 Kusserow, M., Amft, O., & Troster, G. (2013). Monitoring stress arousal in the wild. *Pervasive*  
 527 *computing*, 12(2), 28-37. doi:10.1109/MPRV.2012.56
- 528 Lazarus, R.S., & Folkman, S. (1984). Stress, coping and adaptation. New York, NY: Springer.
- 529 Manzella, C., & Papazoglou, K. (2014). Training police trainees about ways to manage trauma  
 530 and loss. *International Journal of Mental Health Promotion*, 16(2), 103-116.  
 531 doi:10.1080/14623730.2014.903609
- 532 Maracine, M. (2010). The concept of stress and ways of managing it. *The Young Economist*  
 533 *Journal - Revista Tinerilor Economisti*, 8(14), 69-74.
- 534 Task Force of the European Society of Cardiology and The North American Society of Pacing  
 535 and Electrophysiology (1996). Heart rate variability standards of measurement,  
 536 physiological interpretation, and clinical use. *European Heart Journal*, 17, 354–381.
- 537 Nakao, M. (2010). Work-related stress and psychosomatic medicine. *BioPsychoSocial Medicine*,  
 538 4(4), 1-8, doi:10.1186/1751-0759-4-4
- 539 Orsila R., Virtanen, M., Luukkaala, T., Tarvainen, M., Karjalainen, P., Viik, J., Savinainen, M., &  
 540 Nygård, C.H. (2008). Perceived mental stress and reactions in heart rate variability--a  
 541 pilot study among employees of an electronics company. *International Journal of*

- 542       *Occupational Safety and Ergonomics*, 14(3), 275-283.
- 543       doi:10.1080/10803548.2008.11076767
- 544   Pallant, J. (2011). *SPSS Survival manual: a step by step guide to data analysis using SPSS 4th*
- 545       *edition*. Australia: McGraw Hill Companies.
- 546   Papazoglou, K., & Andersen, J. P. (2014). A guide to utilizing police training as a tool to promote
- 547       resilience and improve health outcomes among police officers. *Traumatology: An*
- 548       *International Journal*, 20(2), 103–111. doi:10.1037/h0099394
- 549   Plarre, K., Raij, A., Hossain, M., Ali, A., Nakajima, M., al'Absi, M., ... Wittmers, L. (2011).
- 550       Continuous inference of psychological stress from sensory measurements collected in the
- 551       natural environment. *Proceedings of the 10th ACM/IEEE International Conference on*
- 552       *Information Processing in Sensor Networks (IPSN)*, (pp.1-12). Chicago, Illinois.
- 553   Reyes del Paso, G. A., Langewitz, W., Mulder, L. J. M., van Roon, A., & Duschek, S. (2013). The
- 554       utility of low frequency heart rate variability as an index of sympathetic cardiac tone: A
- 555       review with emphasis on a reanalysis of previous studies. *Psychophysiology*, 50(3), 477-
- 556       487. doi:10.1111/psyp.12027
- 557
- 558   Rodrigues, J. G., Aguiar, A., Barros, J. (2014). SenseMyCity: Crowdsourcing an Urban Sensor.
- 559       *arXiv:1412.2070*, 1-10.
- 560   Rodrigues, J., Kaiseler, M., Aguiar, A., Cunha, J.P.S., & Barros, J. (2015). A mobile sensing
- 561       approach to stress detection and memory activation for public bus drivers. *IEEE*
- 562       *Transactions on Intelligent Transportation Systems*, 99, 1-10, doi:
- 563       10.1109/TITS.2015.2445314

- Rodrigues, S., Kaiseler, M., & Queirós, C. (2015). Ecological approaches on stress assessment: A systematic review. *European Psychologist*, 20(3), 204–226, doi:10.1027/1016-9040/a000222
- Rodrigues, S., Kaiseler, M., Queirós, C., & Bastos-Pereira, M. (2017). Daily stress and coping among Emergency Response Officers: A case study. *International Journal of Emergency Services*, 6(2), 1-13. doi:10.1108/IJES-10-2016-0019.
- Segerstrom, S. C., & O'Connor, D. B. (2012). Stress, health and illness: Four challenges for the future. *Psychology & Health*, 27(2), 128-140. doi:10.1080/08870446.2012.659516
- Shaffer, F., McCraty, R., & Zerr, C. L. (2014). A healthy heart is not a metronome: an integrative review of the heart's anatomy and heart rate variability. *Frontiers in Psychology*, 5, 1-19. doi:10.3389/fpsyg.2014.01040
- Smith, T. W., & Stone, A. A. (2003). Ecological momentary assessment research in behavioral medicine. *Journal of Happiness Studies*, 4, 35–52.
- Smyth, J., Zawadzki, M., & Gerin, W. (2013). Stress and disease: A structural and functional analysis. *Social and Personality Psychology Compass*, 7(4), 217–227, doi:10.1111/spc3.12020
- Strahler, J., & Ziegert, T. (2015). Psychobiological stress response to a simulated school shooting in police officers. *Psychoneuroendocrinology*, 51, 80-91, doi:10.1016/j.psyneuen.2014.09.016
- Schwab, J.O., Eichner, G., Schmitt, H., Weber, S., Coch, M., & Waldecker, B. (2003). The relative contribution of the sinus and AV node to heart rate variability. *Heart*, 89, 337–338.
- Taelman, J., Vandeput, S., Spaepen, A., & Huffel, S. V. (2008). Influence of mental stress on heart rate and heart rate variability. *IFMBE Proceedings* 22, 1366–1369.

- 587 Trull, T., & Ebner-Priemer, U. W. (2013). Ambulatory Assessment. *Annual Review of*  
 588 *Clinical Psychology*, 9, 4.1–4.27, doi:10.1146/annurev-clinpsy-050212-185510
- 589 Turvey, B. (1995). Police Officers: Control, Hopelessness, & Suicide," Knowledge Solutions  
 590 Library, Electronic Publication, Retrieved from [http://www.corpus-](http://www.corpus-delicti.com/suicide.html)  
 591 [delicti.com/suicide.html](http://www.corpus-delicti.com/suicide.html)
- 592 van Ravenswaaij-Arts, C. M., Kollée, L. A., Hopman, J. C., Stoelinga, G. B., & van  
 593 Geijn, H.P. (1993). Heart rate variability. *Annals of Internal Medicine*, 118,  
 594 436–447.
- 595 Voss, A., Schroeder, R., Heitmann, A., Peters, A., & Siegfried, P. (2015). Short-term Heart Rate  
 596 variability – influence of gender and age in healthy subjects. *Plos One*, 10(3): e0118308.  
 597 doi:10.1371/journal.pone.0118308
- 598 Waters, J. A., & Ussery, W. (2007). Police stress: history, contributing factors, symptoms, and  
 599 interventions. *International Journal of Police Strategies & Management*, 30(2) 169-188.  
 600 doi:10.1108/13639510710753199