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

2   **concept study**

3   [1] Rodrigues, S., [2] Kaiseler, M., [3] Pimentel, G., [4] Rodrigues, J., [5]Aguiar, A., [6] Queirós, C., &

4   [7]Cunha, J.P.S.

5   [1,6] Faculty of Psychology and Educational Sciences, University of Porto, Portugal.

6   [2] Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, UK.

7   [1,3,7] Center for Biomedical Engineering Research (C-BER) of INESC TEC Porto, and Faculty of

8   Engineering, University of Porto, Portugal.

9   [4,5] Institute of Telecommunications, Department of Electronic Engineering and Computers,

10   Faculty of Engineering, University of Porto, Portugal.

11   Author Note:

12   Correspondence should be sent to: Susana Rodrigues. INESC TEC - INESC Technology

13   and Science and FEUP - Faculty of Engineering, University of Porto, Portugal. Rua Dr. Roberto

14   Frias s/n Edifício 1, 4200-465 Porto Portugal Telephone: 22 209 4000 Email:

15   susanarodrigues_@hotmail.com.

16

17

18

19

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

21   study

22   **Abstract**

23   Occupational stress has been widely recognized as a global challenge and has received

24   increased attention by the academic community. Ambulatory Assessment methodologies,

25   combining psychophysiological measures of stress, offer a promising avenue for future

26   prevention and/or rehabilitation stress research. Considering that policing is well known for

27   being a particularly stressful occupation, Emergency Responders Officers (EROs) stress levels

28   were investigated. Particularly, this study analyzed: (i) physiological stress data obtained during

29   shifts and compared these data with baseline levels (days off), as well as (ii) with normative

30   values for healthy populations; (iii) stress symptoms differences from beginning to end of shift;

31   (iv) stress events and events intensity and (v) the acceptability and feasibility of this proof-of-

32   concept study in a highly stressful occupation. A Geo-location event system was used to help

33   retrospective accounts of psychological stress, combined with electrocardiogram (ECG) data and

34   mobile self-reports, that include stress symptoms, event types and event intensity. Results

35   suggest that EROs experience high levels of stress (both on-duty and off duty) when compared to

36   healthy populations. Stress symptoms increase from the beginning to end of the shift. However,

37   the mean events intensity was very low. It can be concluded that stress may not always be

38   diagnosed when using merely self-reports. These findings highlight the importance of combining

39   both self-report and physiological stress measures in occupational health contexts. Finally,

40   results confirm the acceptability and feasibility of the multi-method used. Key implications for

41   policy makers and applied practitioners in the area of occupational health and future research

42   directions are discussed.

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.

88   Although isolated acute stress responses do not inevitably cause chronic disease, health

89   risks are increased when stressors, or the stress response is frequent and/or persists over long

90   stages (Smyth, Zawadzki, & Gerin, 2013). Particularly, the continuous activation of the stress

91   systems can lead to serious modifications on the neuro-autonomic and endocrinal balance,

92   creating higher levels of psychological (i.e., depression, anxiety) and physiological problems

93   (i.e., hypertension, coronary heart disease, gastrointestinal malfunctions, metabolic syndrome)

94   (Fenici, Brisinda, & Sorbo, 2011).

95   Previous studies in occupational health have used a variety of biological markers of

96   stress, such as cortisol (e.g., Collip et al., 2011), HR, HRV (e.g., Dockray et al., 2010), and blood

97   pressure (BP) (e.g., Ewart & Johnson, 2004). However, there seems to be agreement among the

98   academic community that HRV is the most feasible and reliable way to assess stress

99   physiological responses (Task Force, 1996; Healey & Picard, 2005). HRV is a noninvasive

100   measure for cardiovascular monitoring and offers the opportunity to simultaneously investigate

101   associations between psychological processes and physiological reactions (Orsila et al., 2008).

102   The HRV refers to cardiac rate alterations, particularly, the complex variations of both

103   instantaneous heart rate and the series of inter-times between consecutive peaks of the R-wave of

104   the electrocardiogram (ECG) (RR intervals). This variation is controlled by the ANS, which

105   through the parasympathetic and the sympathetic branches, is responsible for adjusting the HR in

106   response to external or internal physical or emotional stimulus (e.g., stress). When HRV is lower,

107   it suggests that control mechanisms are not functioning correctly (van Ravenswaaij-Arts, Kollée,

108   Hopman, Stoelinga, & van Geijn, 1993). Low HRV is of specific interest to psychologists, since

109   it has been linked with poorer self-regulatory mechanisms, due to the connection of the vagal

110   nerve (a key component that determines HRV) to the same neural network involved in emotional

111   regulation (Appelhans & Lueken, 2006; Koval, Ogrinz, Kuppens, Van den Bergh, Tuerlinckx, &

112   Sutterlin, 2013).

113   Despite advances in stress assessment research in the area of occupational health, there

114   are still several challenges to address. First, traditional stress assessment designs are often

115   retrospective and cross-sectional in nature, using mainly self-report measures. Consequently,

116   data collected may be negatively influenced by memory biases or distortions associated with

117   time delays, challenging the validity and reliability of the reports (Segerstrom & O'Connor,

118   2012). Second, laboratory designs are the common used solution to address the limitations

119   presented above, since they avoid retrospective limitations and can add the rigor of an

120   experimental design (Smith & Stone, 2003). However, laboratory experiments fail to represent

121   real-world settings, due to the inherent artificial conditions. Finally, there seems to be a lack of

122   reliable physiological methods that can be used to assess stress responses in applied settings,

123   particularly among emergency professions such as policing (Hickman, Fricas, Strom, & Pope,

124   2011; Kusserow, Amft, & Troster, 2013).

125   Policing is well known for being a stressful occupation (Strahler & Ziegert, 2015),

126   therefore the monitoring of stress among police officers working in real world scenarios seems to

127   be a key research priority. Despite this need, such an investigation presents several challenges

128   since stress responses can vary across individuals, situations, stressor typologies and can occur at

129   random times, varying in duration and intensity (Kusserow et al., 2013). Although much work

130   has been conducted to better understand police stress, most of these studies relied mainly on self-

131   report measures. An exception is a study by Hickman et al. (2011) that aimed to investigate

132   police stress using direct real-time and spacially anchored measurements of an officer´s response

133   to stressors and the sample consisted of one police officer. Although the study demonstrated that

134   continuous measurement of police officers cardiac response during a shift is possible, results

135   were limited by the lack of self-report stress data considered. Hence, raising questions on

136   whether observed HR increases were due to psychological stress or merely increases in physical

137   activity.

138   In order to overcome previous limitations in this area and considering that stress is a

139   complex topic, Rodrigues et al. (2015) argued that work stress investigations should be

140   multidisciplinary in nature and should employ multi-methods research approaches. In other

141   words, studies should include accurate and reliable measurements of stress supported by both

142   psychological and physiological data, preferably synchronized, and contain control technologies

143   for possible confounder variables biasing physiological data. Accordingly, Trull and Ebner-

144   Priemer (2013) proposed Ambulatory Assessment as a new research tool that covers a wide range

145   of assessment methods combining self-report, observational, and physiological/behavioral

146   measurements for data collection during real life settings.

147   The current study used a multi-method ambulatory approach to assess EROs` stress

148   levels. Particularly, this study analyzed: physiological stress data obtained during shifts and

149   compared these data with (i) baseline levels (days off), (ii) normative values for healthy

150   populations, (iii) stress symptoms differences from beginning to end of shift, (iv) stress events

151   and events intensity ratings and (v) the acceptability and feasibility of this multi-method

152   approach within this population. This method synchronizes self-reports and physiological stress

153   data collected in real-time during an entire workday. These data were then compared to a non-

154   work day and all physiological data were then compared with normative values. The method

155   included a geo-located event system with ECG data, using user-friendly, non-intrusive mobile

156   and wearable technology. The geo-location system allowed to monitor stress information in a

157   smartphone, using Global Positioning System (GPS) and contemplated the exact location where

158   the event occurred. The geo-located data were used to facilitate participant´s memory retrieval

159   of stressful events (Rodrigues, Kaiseler, Queirós & Basto-Pereira, 2017). The amount of time

160   participants spent with the equipment, level of compliance, problems/interference reported and

161   their engagement/satisfaction were investigated to test the acceptability and feasibility of this

162   approach.

163   **Method**

164   **Participants**

165   Six male EROs from a national police force in the second largest city of Portugal were

166   recruited from a larger study (N=14) assessing stress and coping (Rodrigues et al., 2017). The

167   EROs mean age was 34.57 years (SD=4.32) Participants performed emergency police duties,

168   since they were part of a rapid intervention team that was on-call 24/7 to intervene in critical

169   situations. All participants had over five years of experience in policing. The exclusion criteria

170   for the study were participants having a history of cardiovascular disease and/or taking

171   prescription drugs known to affect cardiovascular function. Participants were instructed to

172   perform no changes in their daily routine, such as sport activities, caffeine, nicotine and food

173   consumption. The study was approved by the University of Porto ethics committee and the

174   Portuguese National Police Force Board. Participants were instructed about the voluntary nature

175   of participation and the confidentiality of their responses.

176   **Design**

177   A presentation session was organized to explain the aim and protocol of the study,

178   including a psychoeducational component regarding the stress topic. The purpose of this

179   component was to help participants identify stressful events or symptoms. The study instructions

180   were explained to participants face-to-face by the first author, including a detailed demonstration

181   of procedures. Participants were instructed about the voluntary nature of participation and the

182   confidentiality of their responses.

183   Data was collected during one workday (approximately 8 hours) and one non-work day.

184   For non-working days, participants were required to only use an ECG monitor - VitalJacket® to

185   collect ECG baseline data. During these days, participants were instructed to rest as much as

186   possible and avoid participating in rigorous physical activities. After data collection on non-

187   working days, participants were asked about any stressful events experienced; however, nothing

188   was reported. For the workdays, participants were requested to carry the VitalJacket® and a

189   smartphone with a software application (app). EROs provided information regarding stress

190   symptoms, event types and event intensity. A diagram illustrating the study protocol during shifts

191   is shown in Figure 1.

192   FIGURE 1 ABOUT HERE

193   **Materials and measures**

194   **Physiological data**

195   For physiological data collection, a wearable t-shirt incorporating an ECG monitor -

196   VitalJacket® was used (Cunha, 2010; 2012) (see Figure 2). The VitalJacket® is a wearable bio-

197   monitoring device that provides real-time ECG at a sampling rate of 500 Hz, through one lead

198   and a three axis Accelerometer (ACC). The ACC is an inertial sensor that measures body´s

199   acceleration in 3-axis (x,y,z). Particularly, when a body changes its position the ACC is able to

200   measure this change, as well as the intensity of the movement. In terms of participants' activity,

201   the ACC gives a movement/activity intensity indication. In terms of mathematics, a simple

202   quadratic mean (quadratic mean=$\sqrt{(acc_x^2 + acc_y^2 + acc_z^2)/3}$) is computed using all three axis

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

204 This sensor is in the VitalJacket® system and records the participant movement intensity while

205 monitoring the ECG. Participants did not report any problems regarding the use of the equipment

206 or any interference it may had with their daily activities.

207   FIGURE 2 ABOUT HERE

208   Physiological stress was assessed based on different components of HRV. These measures

209 followed the guidelines presented by the Task Force (1996), that are feasible for stress

210 assessment:

211 - AVNN - Average of (normal-to-normal) NN intervals that indicate the number of heart cycles

212   observed per temporal interval.

213 - Root Mean Square of Differences between successive NN intervals (RMSSD) - This value is

214   obtained by first calculating each successive time difference between heartbeats in

215   milliseconds. Then, each of the values is squared and the result is averaged before the square

216   root of the total is obtained. The RMSSD reflects the beat-to-beat variance in heart rate and is

217   the primary time domain measure used to estimate the vagally-mediated changes reflected in

218   HRV (Shaffer, McCraty, & Zerr, 2014).

219 - pNN50 - the percentage of the number of times per hour in which the change in consecutive

220   normal sinus (NN) intervals exceeds 50 milliseconds; this measure facilitates assessment of

221   parasympathetic (vagal) activity from 24 hour ECG recordings (Ewing, Neilson, & Travis,

222   1984).

223 - Low Frequency (LF) - is a band of power spectrum ranging between 0.04 and 0.15 Hz. and it

224   is used as an accurate reflection of sympathetic activity (Reyes del Paso, Langewitz, Mulder,

225   van Roon, & Duschek, 2013).

226   - High Frequency (HF) - is a band of power spectrum ranging between 0.15 and 0.4 Hz. This

227   represents an index of cardiac parasympathetic tone (Reyes del Paso et al., 2013).

228   - LF/HF Ratio - this is the ratio between the power of Low Frequency and High Frequency

229   bands. This measure indicates overall balance between sympathetic and parasympathetic

230   systems. Higher values reflect domination of the sympathetic system, while lower ones

231   suggest domination of the parasympathetic system.

232   Decreased values of AVNN, RMSSD and pNN50 are indicative of stress. Additionally,

233   increased values of LF and LF/HF are also indicators of stress (Castaldo et al., 2015). Table 1

234   describes these HRV parameters and their trend under stress.

235   TABLE 1 ABOUT HERE

236   **Self-report data**

237   Demographic and medical surveys were used in order to assess participants' current

238 health status and assure that the inclusion criteria were fulfilled. A smartphone with a software

239 application (app), based on the SenseMyCity crowd sensing platform (Rodrigues, Aguiar, &

240 Barros, 2014) was used. This platform consists of an app using smartphones, that includes a back

241 office and a front office and collects real time data from embedded sensors (e.g., GPS,

242 accelerometer, among others). This app allows participants to describe events, and rate stress

243 levels and symptoms (see Figure 3).

244   FIGURE 3 ABOUT HERE

245   **Stress symptoms**

246   In order to understand the cognitive and physical symptoms of stress, a questionnaire was

247 used. This instrument included four questions related with physical ("1- Muscular tension"; "2-

248 Eye fatigue or heavy head"; "3- Nausea, abdominal discomfort and stomach pain"; "4- Difficulty

249   in maintaining the body straight") and cognitive aspects ("5- Concentration problems"; "6-

250   Difficulty in reasoning, thinking or answering"; "7- Affliction or nervousness"; "8- Difficulty in

251   maintaining control"). Participants were asked to rate each item on a Likert-type scale ranging

252   from 0 – "*Not felt at all*" to 4- "*Extremely felt*". These questions were fulfilled in the software

253   app (based on Cohen & Williamson, 1988) at the beginning and end of the day, aiming to

254   evaluate whether there were alterations in stress symptoms experienced in these two moments.

255   **Event type**

256   Type of events experienced during shifts were assessed by selecting an option from a

257   stressor checklist (Drug traffic; Public disorder; Neighborhood intervention; Vehicles chase;

258   Inadequate resources; Other). For the purpose of this paper, stressful situations were defined as

259   "a situation that taxes or exceeds one´s personal resources or threatens the person wellbeing has

260   the potential to cause stress"(Lazarus & Folkman, 1984; p.19). The stressor checklist was

261   developed following pilot work (see Rodrigues, Kaiseler, Queirós, & Basto-Pereira, 2017). This

262   pilot work included a study where 14 ERO´s completed daily diaries over 11 working days. Each

263   diary entry included an open-ended question, where participants reported the most common

264   stressors, these answers formed the stressor checklist for this study.

265   **Event intensity**

266   Stress intensity levels were assessed for each event using a 5-point Likert-type scale

267   ranging from 1- "*Not at all stressful*" to 5 - "*Extremely stressful*". (Kaiseler, Queirós, Passos, &

268   Sousa, 2014). Single–item measures were used since they present several benefits, for a detailed

269   review of these please see Fisher, Matthews, and Gibbons (2016).

270   **Geo-location data**

271   All data gathered with the smartphone were exported to a web server to be processed. The

272   processed ECG data, together with the GPS information and the Google Earth platform

273   information were used to display the location history for the full shift for each participant (see

274   Figure 4). Each reported event and other potential stressful events were detected thorough an

275   automated algorithm (following Rodrigues, Kaiseler, Aguiar, et al., 2015) and were imported into

276   Google map. These events were then presented to participants at the end-of-shift interview,

277   aiming to facilitate memory recall and help on a more accurate description of stressful events as

278   described in Rodrigues et al. (2015) (see details in Figure 4).

279   FIGURE 4 ABOUT HERE

280   **Data analysis**

281   **Physiological data analysis**

282   A software including an algorithm following Pan Tompkins´s work (Pan & Tompkins,

283   1985) was used to analyze ECG data (Biodevices S.A). All HRV metrics (AVNN, RMSSD,

284   pNN50, LF, LF/HF) were computed using 5 minutes' windows, without overlapping and

285   excluding participant's movement data. HRV metrics were compared during shifts and days off

286   and were also compared to healthy individual's normative values following Voss, Schroeder,

287   Heitmann, Peters, and Siegfried (2015) study. This study included the largest population of

288   healthy individuals (N=1,906) and aimed to analyze age and gender related HRV differences.

289   **Self-report data analysis**

290   Self-reported data collected using the smartphone and end-of-shift interviews were

291   subject to a quantitative between-person variation analysis, centered on an event-based approach.

292   Quantitative data from stress symptoms questionnaires were analyzed using a non-parametric

293   hypothesis test – the Wilcoxon Signed Test - conducted using IBM SPSS AMOS (v.22) software.

294   This test was used to compare participants´ stress symptoms mean scores at the beginning and

295   end of shifts. A value of $p < .05$ (two tailed) was considered statistically significant. The internal

296   consistency for the 8 questions of the stress symptoms questionnaire was calculated using

297   Cronbach's alphas. This value provides a coefficient of reliability, and is used as a measure of

298   internal consistency for participants' answers. As recommended these values should be above

299   0.70 (Pallant, 2011). In the current study, the Cronbach's alphas were 0.94. Quantitative event

300   intensity levels were calculated considering the mean intensity of each event.

301   **Geo-location event-system analysis**

302   The geo-located event system analyzed physiological data and monitored potential

303   stressful events based on the cardiac signal retrieved from the VitalJacket®. The ECG data were

304   divided in blocks of 100 seconds and processed using the HRV Toolkit from Physionet

305   (Goldberger et al., 2000). This is a rigorously validated package of open source software for

306   HRV analysis, including visualization of NN interval time series and automated outlier removal.

307   These HRV statistics are well accepted among scholars (e.g., Castaldo et al., 2015). The system

308   extracted HRV metrics, analyzed them and selected the places (using GPS) where a potentially

309   stressful event occurred. These events were selected from all the moments the EROs reported an

310   event on the app, combined with the blocks having the highest algorithms of HRV's LF power,

311   but separated by at least 5 minutes from each other.

312   **Results**

313   **Physiological data**

314   A total of 47h of annotated ECG recordings during shifts and 30h of data during days off

315   were collected and analyzed, resulting in a total of 77h of high medical grade ECG signal.

316   Results from AVNN, RMSSD and pNN50 mean values were lower than normative values

317   when participants were on duty. The mean LF/HF ratio was higher than normative values for

318   both shifts and days off (Figure 5). Additionally, two examples of this ECG signal analysis

319   during specific events ("Driving fast"; "Gun situations" – Table 2) provided by the EROs also

320   indicate the presence of physiological stress, considering the high values of LF/HF and low

321   values of AVNN and pNN50 (Figure 6 a) and b).

322   FIGURE 5 ABOUT HERE

323   FIGURE 6 ABOUT HERE

324   TABLE 2 ABOUT HERE

325   **Self-report data**

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

327   Regarding stress symptoms, results from the Wilcoxon Signed Test showed no

328   statistically significant change for physical and cognitive stress between the beginning and end

329   of shift symptoms (Z= -1.60, p >.05 and Z=.37, p >.05, respectively). However, the overall mean

330   score of stress symptoms was higher at the end of the shift (*M*=1.73; *SD*=.85) compared with the

331   beginning of shift (*M*=1.50; *SD*=.51)

332   **Event intensity**

333   Stress events reported and respective stress intensity levels are presented in Table 2.

334   Regarding quantitative stress intensity measures, the stress intensity scores ranged from 0 to 5,

335   and the overall mean was 2.1 (*SD*=.99). "Suspect escape" was the most intense stress event

336   reported (*M*=4.0), followed by "Public disorder (*M*=3.0) and "Gun situation" (*M*=3.0).

337   **Geo-located event system**

338   In total nine events were reported by all EROs using the geo-located system (Table 2).

339   The most cited event type was "neighborhood interventions" (cited three times), followed by

340   "Public disorder" situations (cited two times).

341   **System acceptability and feasibility**

342   All participants (100%) carried out the study "kit" during both a shift and a day off and

343   did not report any problems regarding usage or interference with daily activities. Regarding the

344   use of the software app, the majority of participants (five in six; 83%) forgot to use it after a

345   stressful event. An exception was only one stressful event that was reported on duty by one

346   officer. In what concerns to the use of the software app to assess stress symptoms at the

347   beginning and end of the shift, out of the six, five EROs (83%) completed the questionnaires on

348   both occasions.

349   **Discussion**

350   The current study used an ambulatory multi-method approach to assess

351   psychophysiological stress responses in occupational health field and aimed to test the

352   acceptability and feasibility of this method in a sample of EROs. Particularly, this study

353   investigated: (i) physiological data obtained during shifts and compared these data with baseline

354   levels (days off), as well as (ii) with normative values for healthy populations; (iii) stress

355   symptoms differences from beginning to end of shift; (iv) stress events and events intensity and

356   (v) the acceptability and feasibility of this proof-of-concept study among a highly stressful

357   profession.

358   Findings provide an insight on psychophysiological stress levels of EROs when working

359   under real world conditions and confirm the acceptability, feasibility and research potential of the

360   method to be used in similar emergency occupational settings.

361   The physiological analysis suggested that EROs experienced high levels of physiological

362   stress, when compared to baseline levels (days off) and when compared to healthy individuals

363   based on the study conducted by Voss et al. (2015). With the exception of Voss and colleagues'

364   paper, it is important to highlight the inexistence of studies including normative values of HRV

365   in large healthy populations. Furthermore, to the best of our knowledge, this is the first study to

366   provide police officers` HRV measures while working in real world conditions, highlighting the

367   original contribution of the findings to this body of knowledge. The physiological analyses

368   indicate stress based on the decreased values of AVNN, RMSSD and pNN50 that reflected a

369   depressed HRV during stress (Castaldo et al., 2015). Finally, the LF/HF ratio was higher than

370   normative values, whether the participants were on-duty or off-duty. Higher values reflect

371   domination of the sympathetic system, while lower ones refer a higher activity from the

372   parasympathetic system, which is compatible with stress responses (Kaur, Bhalla, Bajaj, Sanya,

373   & Babbar, 2013).

374   Regarding EROs psychological stress symptoms at the beginning compared to end of the

375   shift, findings suggest that there was a minor increase in symptoms. However, this was not

376   statistically significant, probably due to the reduced sample size. The observed tendency supports

377   previous work conducted among Portuguese police officers (e.g., Gomes et al., 2012) showing

378   that physical and cognitive stress symptoms increase during the working day, probably due to

379   experience of stress events. These findings suggest that this population may be experiencing

380   potential cumulative stress effects along the days. Future longitudinal studies are required to

381   confirm this assumption. Additionally, despite the fact that findings suggest the experience of

382   higher stress symptoms at the end of the shift, five out of six EROs participating in the current

383   study did not rate any experienced events as stressful. These findings may suggest that EROs

384   may not be aware of their stress and its impact on their health and may therefore be unlikely to

385   ask for help.

386   Accordingly, the results of the ECG analysis (using AVNN, pNN50 and LF/HF metrics)

387   performed during specific events showed that, particularly for "Gun situations", physiological

388   stress was evident in the ECG signal, but this event was not rated as stressful. It is crucial to

389   highlight the importance of the current multi-method approach to understand these compiling

390   findings. Particularly, if only self-report measures were used, one could potentially reach the

391   premature conclusion that EROs do not experience stress events. Hence, combining

392   psychophysiological measures of stress seems to be key to fully understand these professional's

393   occupational health while working under real world conditions.

394   A possible explanation for the fact that EROs do not rate events as stressful could be due

395   to the fact that those events are regularly experienced by them during their shifts, therefore they

396   do not perceive them as stressful, but rather as a routine part of their daily work. An alternative

397   explanation for these findings could be related to the police culture. As stated by Turvey (1995)

398   an officer is expected, by his culture to endure, not to talk about problems or concerns with

399   others. Officers are expected to maintain a surface immunity to their own humanness. When a

400   police officer expresses psychosocial stress, this could be viewed as a weakness, therefore they

401   do normally avoid reporting it (Anshel, 2000). Further qualitative research designs are required

402   to fully understand EROs appraisal of stress events in real world.

403   These findings should be useful for practitioners working with police officers. It is

404   recommended that police practitioners work collaboratively with officers to combat the stigma of

405   mental health problems and treatment, by normalizing help-seeking behavior (Papazoglou &

406   Andersen, 2014). Additionally, future interventions for this population could include the

407   development of peer-to-peer programs, since previous research has shown that officers seem

408   reluctant to look for clinicians (Manzella & Papazoglou, 2014; Waters & Ursury, 2007).

409   Regarding the acceptability of this study, this was assessed considering the use of the

410   equipment and the engagement with the methodology. All officers carried the study "kit" all day,

411   without reporting any disturbance with the equipment, demonstrating the high acceptability and

412   feasibility of this method. In regards to the use of the geo-located system, in agreement with

413   Rodrigues et al. (2015) findings among bus drivers, this method seems to facilitate memory

414   retrieval among EROs when identifying stressful events. Other possible future advantage in GPS

415   location tagging could be the chance to have this data available in real time allowing for police

416   commanders to have a better control of their teams and it would be easier to identify stressful

417   hotspots (e.g., dangerous neighborhoods, roads). Additionally, from an implementation

418   perspective this system may be a tool to provide citywide "stress maps", spotting areas in need

419   for an emergency response or a local authority intervention. It is recommended that future studies

420   should test the functionality of the system with different professionals working in urban mobile

421   environments.

422   The current ambulatory multi method approach seems to be a promising tool to support

423   first responders' occupational health diagnostic and interventions while also informing

424   management decisions in real time. The current method was key to understand occupational

425   stress among EROs and findings provide key practical and methodological implications.

426   Considering the contemporary increased demands on security, officers` stress monitoring during

427   real world events should be at the forefront of occupational research priorities. Furthermore, our

428   findings suggest that police practitioners should implement healthy routines (e.g., healthy eating

429   habits, exercise and lifestyle), monthly medical and physical monitoring, and group sessions for

430   stress symptoms detection, aiming to help officers cope more efficiently with daily stress.

431   The current study is not without limitations. First, is the low level of compliance for

432   specific kinds of data, such as the little use of the software app following events. This could be

433   due to the fact that EROs do not perceive events as stressful. Alternatively, they could be too

434   involved in daily events, restricting their capacity for study compliance. A possible solution to

435   overcome this challenge is to have an audible/vibrating alert system in the smartphone, capable

436   of detecting changes in HRV parameters after a stressful event, and warning EROs to fulfill a

437   quick stress survey. Alternatively, participants could report events only at the end of the shift

438   using the geo-located event system. Second, the small sample size, and short time duration of

439   data collection should also be acknowledged as limitations. Finally, it is also important to

440   acknowledge that this type of methodology is resource intensive in terms of software, technology

441   and expertise (i.e., psychology, biomedical and informatics).

442   Despite these limitations, we believe that our 77h of geo-located data is one of the largest

443   datasets obtained with police officers, and our results point to some promising avenues for future

444   research and practice that can be used with larger samples and different occupational groups.

445   Hence, findings from the current study extend the body of knowledge of occupational stress

446   assessment and provide a feasible and accurate methodology allowing a holistic approach to

447   stress assessment among highly stressful professions working under real world conditions.

448

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

450   conflict of interest.

451

452   References

453

454   Anshel, M. H. (2000). A conceptual model and implications for coping with stressful events in

455   police work. *Criminal Justice Behavior, 27*(3), 375-400.

456   Appelhans, B.M., & Luecken, L.J. (2006). Heart rate variability as an index of regulated

457   emotional responding. *Review of General Psychology, 10,* 229–240. doi:

458   10.1037/1089-2680.10.3.229

459   Biodevices, S.A. (n.d.). Certifications. Retrieved from http://www.vitaljacket.com/?page_id=144

460   Cannon, W. B. (1914). The emergency function of the adrenal medulla in pain and the major

461   emotions. *American Journal of Physiology, 33*, 356-372.

462   Cartwright, S. & Cooper, C. L. (1997). *Managing workplace stress.* Thousand Oaks,

463   CA: Sage Publications.

464   Castaldo, R., Melillo, P., Bracale, U., Caserta, M., Triassi, M., & Pecchia, L. (2015). Acute

465   mental stress assessment via short term HRV analysis in healthy adults: A systematic

466   review with meta-analysis. *Biomedical Signal Processing and Control,18,* 370-377. doi:

467   http://dx.doi.org/10.1016/j.bspc.2015.02.012

468   Cohen, S., & Williamson, G. M. (1988). Perceived stress in a probability sample of the

469   United States. In S. Spacapan & S. Oskamp (Eds.), *The social psychology of health*

470   (pp. 31-67). Newbury Park, CA: Sage.

471   Collip, D., Nicolson, N. A., Lardinois, M., Lataster, T., van Os, J., & MyinGermeys, I. (2011).

472   Daily cortisol, stress reactivity and psychotic experiences in individuals at above average

473   genetic risk for psychosis. *Psychological Medicine, 41*, 2305-2315.

474   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. S*tudies 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. I*ndian 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. T*raumatology: 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

564 Rodrigues, S., Kaiseler, M., & Queirós, C. (2015). Ecological approaches on stress assessment: A

565   systematic review. *European Psychologist, 20*(3), 204–226, doi:10.1027/1016-

566   9040/a000222Rodrigues, S., Kaiseler, M., Queirós, C., & Bastos-Pereira, M. (2017).

567   Daily stress and coping among Emergency Response Officers: A case study. *International*

568   *Journal of Emergency Services, 6*(2), 1-13. doi:10.1108/IJES-10-2016-0019.

569 Segerstrom, S. C., & O´Connor, D. B. (2012). Stress, health and illness: Four challenges

570   for the future. *Psychology & Health, 27*(2), 128-140. doi:10.1080/08870446.2012.659516

571 Shaffer, F., McCraty, R., & Zerr, C. L. (2014). A healthy heart is not a metronome: an integrative

572   review of the heart's anatomy and heart rate variability. *Frontiers in Psychology, 5,* 1-19.

573   doi:10.3389/fpsyg.2014.01040

574 Smith, T. W., & Stone, A. A. (2003). Ecological momentary assessment research in

575   behavioral medicine. *Journal of Happiness Studies, 4,* 35–52.

576 Smyth, J., Zawadzki, M., & Gerin, W. (2013). Stress and disease: A structural and functional

577   analysis. *Social and Personality Psychology Compass, 7*(4), 217–227,

578   doi:10.1111/spc3.12020

579 Strahler, J., & Ziegert, T. (2015). Psychobiological stress response to a simulated school shooting

580   in police officers. *Psychoneuroendocrinology, 51*, 80-91,

581   doi:10.1016/j.psyneuen.2014.09.016

582 Schwab, J.O., Eichner, G., Schmitt, H., Weber, S., Coch, M., & Waldecker, B. (2003). The

583   relative contribution of the sinus and AV node to heart rate variability. *Heart, 89,* 337–

584   338.

585 Taelman, J., Vandeput, S., Spaepen, A., & Huffel, S. V. (2008). Influence of mental stress on

586   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-

591   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