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Effects of psychological stress test on the cardiac response of public safety workers: alternative parameters to autonomic balance

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Abstract. It is well known that public safety workers (PSW) face many stressful situations that yield them as high-risk population for suffering chronic stress diseases. In this multidisciplinary research the cardiac response to induced psychological stress by a short duration Stroop test was evaluated in 20 female and 19 male PSW, in order to compare traditionally used cardiac response parameters with alternative ones. Electrocardiograms have been recorded using the Eindhoven electrodes configuration for 1 min before, 3 min during and 1 min after the test. Signals analysis has been performed for the heart rate and the power spectra of its variability and of the variability of the amplitude of the R-wave, i.e. the highest peak of the electrocardiographic signal periodic sequence. The results demonstrated that the traditional autonomic balance index shows no significant differences between stages. In contrast, the median of the area of the power spectrum of the R-wave amplitude variability in the frequency region dominated by the autonomous nervous system (0.04-to-0.4 Hz) is the more sensitive parameter. Moreover, this parameter allows to identify gender differences consistent with those encountered in other studies.

1. Introduction

Electrocardiograms are the most frequently used cardiac electric signals because of their noninvasive character and the information they can provide. The characteristic shape of an electrocardiogram (ECG) consists of a periodic sequence of a succession of alternating local maxima and minima denoted as PQRST complex that are presented in each heartbeat. The central peak maximum, usually the highest peak of the complex when using the Eindhoven electrodes configuration, is known as R-wave. This complex is due to the different phases of depolarization, repolarization and electrical recovery in the atria and ventricles of the heart. However, due to the characteristics of the measurement, the respiratory function also influences the ECG-signal [1-3].

Among the parameters that can be obtained from an ECG, the heart rate (HR) or cardiac frequency is one of the most important. It is the reciprocal of the time intervals among successive R peaks, also known as RR intervals. In an individual there is a natural variation in the RR intervals

and therefore in the HR. Such variability is known as heart rate variability (HRV) [2, 3]. Another parameter, among others, that is usually extracted from the ECG, although strongly influenced by the thoracic movements during respiration, is the height of the R-wave with respect to the baseline of the signal. This parameter is known as R-wave amplitude, and is related to changes on the volume of the left ventricle [4, 5].

The ECG signals are mediated by the autonomic nervous system (ANS) through the sympathetic (SNS) and parasympathetic (PSNS) nervous system [6]. Thus, stimuli that influence the ANS of an individual affect its electrocardiographic signal. The differences can be interpreted with respect to the ECG baseline as the individual's response to such stimulus. As a result, the ECG can be used to assess the level of stress experienced by a subject. To this aim, the most commonly used analyses employ the HRV and to a lesser extent, any other obtainable ECG parameters such as the amplitude of the R-wave or the QT interval (time interval between the peaks Q and T within a given PQRST complex) [7,8].

In the assessment of stress by HRV, the power spectrum of the variation of the RR intervals of the ECG, obtained by the fast Fourier transform (FFT) is firstly determined. Then the two areas under the curve of this spectrum within the so-called "low" and "high" frequency ranges, defined according to international standards of HRV analysis, are considered [9]. The low frequency (LF) region ranges from 0.04 to 0.15 Hz, while the high frequency (HF) interval goes from 0.15 to 0.4 Hz.

It has been determined that the LF range is associated to the SNS activity, whereas within the HF region both the SNS and PSNS are involved, and consequently the whole LF + HF region is dominated by the ANS [9]. The ratio of the LF to the HF areas define what is known as (autonomic) balance index (BI) of the ANS, which is influenced for states of anxiety and stress [6,10,11]. Another common way to observe the ANS behavior is through the so-called Poincare plot of the HR, which is a graph that reflects the dispersion of the data. In this case, the set of segments RR (in pairs) is brought into a two-dimensional plot, in which the abscissa of point n is given by the interval R_n-R_{n+1} (or the corresponding HR(n)) and its ordinate by the following R_{n+1}-R_{n+2} interval (or HR(n+1)), so that a delay map is obtained. In the plot a roughly elliptical shaped group of data is usually obtained, so that up to a certain percentage the data can be enclosed in an ellipse. The longitudinal diameter or major axis (with positive slope) of the ellipse describes the deviation of the long-term HR, whereas the cross-sectional diameter or minor axis (negative slope) characterizes the changes in the HR. With help of both values, it is the possible to quantify spontaneous and long-term changes of the HRV [12,13]. HRV has been used in some studies related with psychological stress in wich the authors use the usual parameters as well as alternative methodologies of measurement [14].

In this investigation we measured and evaluated the cardiac response of a sample of male and female public safety workers (PSW) subjected to induced psychological stress by a short duration Stroop test [15]. PSW face many stressful situations that yield them as high-risk population for suffering chronic stress diseases. Objectives of the study were to determine whether the traditionally used parameters for stress-psychological assessment through the cardiac response were sensitive enough for this test and sample, and to compare them with alternative parameters. Results are additionally discussed in terms of differences between the groups of male and female subjects.

2. Methodology

This study was approved by the Department of Public Safety (DPS) of Leon, Guanajuato, and for the Division of Health Sciences Campus León, from the University of Guanajuato, Mexico. For purposes of comparison the same methodology applied in previous studies [16] has been used here. Written informed consent was obtained from all volunteers, and the study was conducted according to the guidelines outlined in the Declaration of Helsinki World Medical Organization, 1996 [17].

The procedures were explained to the volunteers and the evaluations were done during the morning (from 8:00 to 14:00) at the DPS of Leon, Guanajuato, Mexico.

A group of 20 women and 19 men from 18 to 40 years of age was studied in an experimental clinical trial. The sample of volunteers was a randomly selected from a universe of 1000 polices of the DPS of Leon, Guanajuato, Mexico. Workers belong to a medium low socioeconomic level which was determined as in our previous study [16]. Inclusion criteria considered only subjects who had at least nine years of schooling level, without cardiovascular, neither endocrine or psychiatric illnesses that could affect the variables studied, and also with non-antecedents of use of any drug or medication which may have effects in the central nervous system or at the cardiovascular level. Volunteers were divided in two groups according to gender. Before starting the experiment, clinical assessments were conducted for all subjects.

ECG signals from each participant were recorded at three different stages in the study: before (initial stage: 1 min), during (test stage: 3 min), and after (final stage: 1 min) the Stroop test. During the Stroop test words in colour are projected upon a screen at the rate of one word per second. The subject was asked to speak up the colour of the word. During the first 40 s, words of several objects were projected on a scream, followed by one minute of words that name colours. The written colour sometimes corresponds to the colour of the word and sometimes does not. Finally, again words of several objects, excluding names of colours are shown [18,19]. During the whole measurement, the subjects rest in a supine position having a light slope in order to let them comfortably read the projected words on the screen. The electrodes are positioned in the Eindhoven configuration and the ECG measurements performed with a BIOPAC MP150 system and corresponding ECG module.

From the recorded ECG signals the R-wave amplitudes have been considered additionally to the RR time intervals, from HR and the HRV have been determined. The usual autonomic BI has been obtained from the HRV power spectrum (BI of the HRV). Poincare parameters for the HR have also been considered for each subject and experimental stage using 95 % data inclusion for the Poincare ellipse. Additionally, the HRV-related alternative parameters of relative area LF to the total area LF + HF, and the median of this total area have been defined for both the HRV and the power spectrum of the variability of the R-wave amplitude or simply R-wave variability (RWV). For the RWV an alternative BI (BI of the RWV) has been analogously defined as the usual BI, as the rate between the corresponding LF and HF areas.

For the complete data set, differences among stages were tested using dependent t-test. Significance was considered when p was < 0.05. Statistical analysis was performed with STATISTICA, Stat-Soft, Inc. Tulsa OK, version 7.0 and all plots were generated with Origin Pro 8.0.

3. Results and discussion

Figure 1 shows typical results for one subject during the three experimental stages. In figure 1a the plot of the HR can be seen. Here, the high HRV before and after the Stroop test is illustrated. For the test stage, the HR typically rises, whereas the HRV diminishes for most the volunteers. This indicates that the Stroop test does work as stressor even for SSP, as other studies confirm [15]. The diminishing of the HR and the slight increase of its variability during the last part of the test stage apparently come from a partial relaxation of the subject. In the Poincare plot shown in figure 1b, as expected, the data are distributed in three regions of roughly elliptical shape for each stage. The plot shows that in comparison to the data obtained for the initial stage (black circles), the points corresponding to the test stage (white squares) not only present a shift to higher HR values but the ellipse that can enclose them is narrower. For the final stage, the dots of the Poincare plot return to lower HR values. These results are consistent with the results observed in figure 1a.

In figure 2 the results for the HRV analysis for the groups of men and women for all

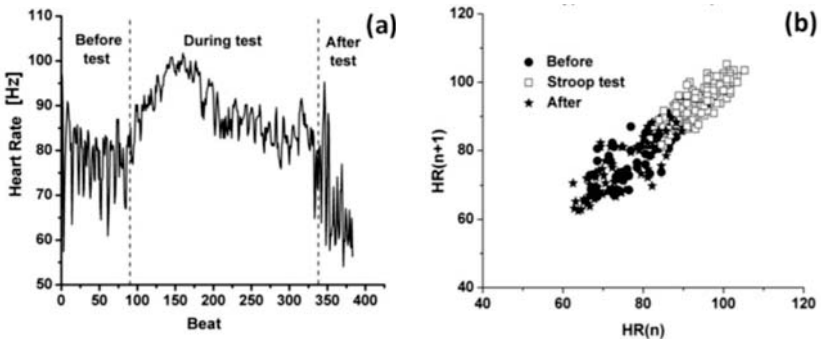

Figure 1. Typical results for one subject for (a) the HR, and (b) the HR delay map (Poincare plot) for all experimental stages.

experimental stages are shown. There are not any statistically significant (SS) differences neither between the different stages nor between the gender groups for neither the BI, relative area LF / (LF + HF) nor median of total area LF + HF.

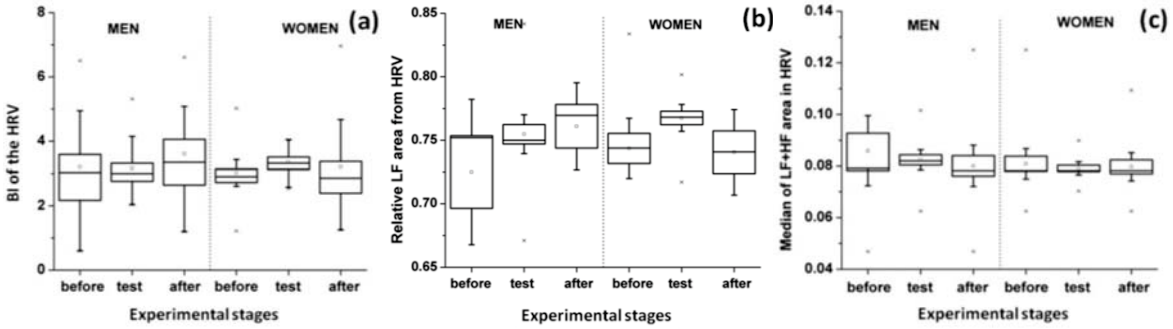

Figure 2. Results obtained for the HRV analysis for men and women for all experimental stages. **(a)** Autonomic balance index. **(b)** Relative area LF / (LF + HF). **(c)** Median of total area LF + HF.

For the BI (figure 2a) however, for both the genders a slight tendency to increase between the initial and the test stages is observed This tendency is more noticeable and with less statistical dispersion for the women than for the men. However, whereas this rising tendency holds for men during the final stage, for the women a diminishing tendency is observed after the Stroop test. As for the relative area LF to LF + HF (figure 2b), the same tendencies described for the BI of the HRV are also here observed although in a more emphasized way.

The increases observed in the BI and in the relative area LF to LF + HF between the initial stage and the test stage indicate that, according to [5] and [15], the Stroop test generates a response of the sympathetic nervous system of the subjects. As a consequence, the medians of the total areas LF + HF shift to the LF region, where the SNS dominates, as is shown in the box plot of figure 2c. Here, the tendencies between stages agree with those expected in presence of stress and do not indicate any gender difference besides the different intensity of the changes between stages and the less dispersion obtained for the group of women. However, like for the former parameters extracted from the HRV, lack of significance is observed. A likely explanation of this is that some partial relaxation mechanism sets on during the Stroop test, as suggested by the cardiac frequency diminishing observed in figure 1 during this test stage.

The group results of the Poincare plots analysis are summarized in figure 3 as box plots of the Poincare ellipses semi-axes obtained for the three experimental stages and both the genders. In contrast to the parameters obtained from the HRV analysis the Poincare parameters do show differences that are statistically significant or at least in the limit of significance. For the semi-major axis, more directly associated with changes in the HR, the SS changes take place between the initial and both the test and final stages for both genders. For the semi-minor axis, Y, directly associated with changes in the HRV, the most important changes occur between the final and the previous stages. These changes are SS for men and *quasi*-SS for women. Contrast in the tendencies of the changes between the different stages between men and women are to be noticed. These partially SS results seem to point out that whether men relax after the test, women do not.

The results for the RWV analysis for the groups of men and women for all experimental stages are shown in figure 4. Similarly as for the Poincare parameters, and in contrast to the results for the HRV analysis, these parameters present SS changes. Among all parameters analyzed in this work, the median of the total area LF + HF obtained from the RWV (figure 4c) shows the largest number of SS differences between stages.

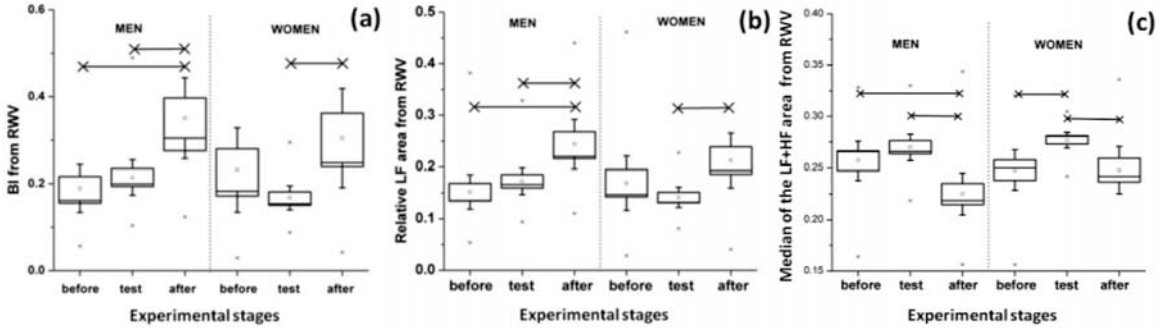

Figure 4. Results obtained for the RWV analysis for men and women for all experimental stages. **(a)** Analogous balance index. **(b)** Relative area LF / (LF + HF). **(c)** Median of total area LF + HF. The horizontal solid (dot-) lines indicate SS (or *quasi*-SS) differences between stages marked with large crosses.

The SS differences shown by the BI and the relative area LF to LF + HF of the RWV (figures 4a and 4b) are referred to the final stage for both genders. This indicates that since the R-wave amplitude is influenced by respiration, a larger relaxation is obtained after the Stroop test than before or during the test. It is however very remarkable that for the median of the total area LF + HF (figure 4c) this does not happen for the women group. For this case, the referent for SS changes is the test stage.

It is important to mention that there are several studies that indicate the existence of gender differences in the response to stress [20,21]. Nevertheless, for the short test presented here, it is found that gender response difference is not clearly recognizable either from the BI nor from any of the other HRV considered parameters. Gender differences can be seen from the Poincare analysis, which only gives information of non-parametric values (ranges). From the median of the total area

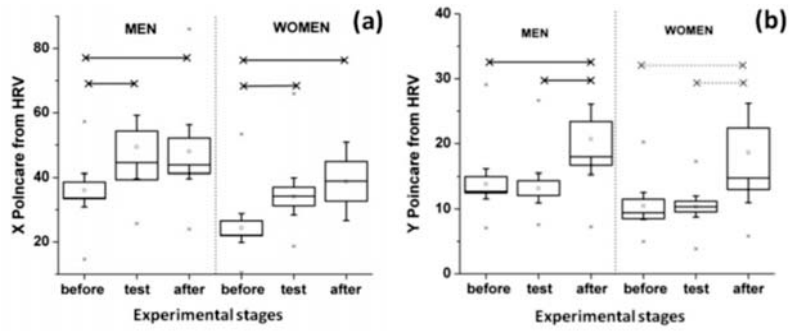

Figure 3. (a) Semi-major and **(b)** semi-minor axes of the HR Poincare analysis for both genders and all experimental stages. The horizontal solid (dot-) lines indicate SS (or *quasi*-SS) differences between stages marked with large crosses.

LF + HF of the R-wave variability it is evidenced that the response to acute stress, as the induced by Stroop test, has similar behaviors in both genders (figure 4c), but for the women group, the differences are higher for women than for men, which is again in agreement with published results [20-23].

4. Conclusion

Here we confirm that the Stroop test is an appropriate procedure to evaluate the psychological stress response through analysis of the ECG signals. To this aim however, appropriate ECG signals parameters have to be considered. We found that neither the HRV, nor the BI, nor the here proposed HRV-related alternative parameters present SS changes during the stages of the test. SS gender differences are also not shown by any of these parameters. In contrast, the RWV and the Poincare plots do identify SS changes due to the Stroop test and allow to observe gender differences. From all the analyzed parameters, the median of the total LF + HF area of the RWV is the more sensitive. It also permits to identify gender differences consistent with those encountered in other studies.

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