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The effects of exposure to environmental factors on Heart Rate Variability: An ecological perspective

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ABSTRACT

The impact of human exposure to environmental factors on Heart Rate Variability (HRV) was examined in the urban space of Tel-Aviv-Jaffa. Four environmental factors were investigated: thermal and social loads; CO concentrations and noise. Levels of HRV are explained mainly by subjective social stresses, noise and CO. The most interesting result is the fact that while subjective social stress and noise increase HRV, low levels of CO are reducing HRV to some extent moderating the impact of subjective social stress and noise. Beyond the poisoning effect of CO and the fact that extremely low levels of HRV associated with high dozes of CO increase risk for life, low levels of CO may have a narcotic effect, as it is measured by HRV. The effects of thermal loads on HRV are negligible probably due to the use of behavioral means in order to neutralize heat and cold effects.

1. Introduction

A growing body of literature has been focusing during the last years on the combined effects of several environmental factors on stress and health. Many of these researches focus on the impact of environmental factors on the subjective sense of discomfort and were conducted in indoor micro-environments (Clausen et al., 1993; Federspiel, 2001; Federspiel et al., 2002; Toftum, 2002; Fang et al., 2004) and work places (Kirstel-Boneh et al., 1995; Rashid and Zimring, 2008) or on soldiers in extreme outdoor conditions (Epstein et al., 2000; Kjelberg and Landström, 1994). Such environments, researchers assume, are easier to control. However, these studies do not provide information on the effects of environmental factors on the human sense of discomfort in regular urban daily life. Research has uncovered some positive relationships between environmental factors like thermal load and noise and sense of discomfort, with minimal interactions between the independent variables (Fanger et al., 1977; Hancock and Pierce, 1985; Clausen et al., 1993; Kirstel-Boneh et al., 1995; Jendritzky et al., 1990; Epstein et al., 2000; Toftum, 2002; Pellerin and Candas, 2003; Candas and Dufour, 2005). Furthermore, two more characteristics of these studies limit the validity of their results: First, the study of human exposure to environmental factors in outdoor environments has been based on data collected from fixed monitoring stations located in just a few dispersed urban positions. Second, most of these studies tested the impact of just one environmental factor on sense of discomfort, with the exception of a few studies that combined two factors such as thermal load and noise (Hancock and Pierce, 1985; Pellerin and Candas, 2003) or thermal load and air pollution (Poupkou et al., 2011).

A large number of studies have revealed that monitoring stations significantly underestimate people's personal exposure to the actual concentrations of air pollution in their daily routine environments (Adamms et al., 2001; Duci et al., 2003; Gullver and Briggs, 2004; Kaur et al., 2005). Concentrations of pollutants in urban spaces differ according to the city morphology, topography, position relative to winds and distance from pollutant sources (Gu et al., 2011; Sun et al., 2012). We argue that actual human exposure to environmental factors differ according to individuals' differing styles of usage of their everyday life spaces in the city (Schnell et al., 2012). Therefore, individuals who are located at even small distances from one another may be differently exposed to environmental pollutants.

Most former studies employed subjective measures of sense of discomfort or stress. These measures do not necessarily reflect the

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physiological aspects of stress (Selye, 1956; Ulrich, 2001; Rashid and Zimring, 2008). When stress is most simply defined as a consequence of the failure of human beings to adequately respond to mental, emotional or physical demands whether actual or imaginary (Selye, 1956). Stress influences, among other things, the performance of the autonomous nervous system that regulates vital processes like the blood circulation and breathing in adapting the body's internal environment to the external one (Jonsson, 2007). In the process, mediated by feelings, information from the surrounding is translated both into internal autonomic and external behavioral reactions. Stress immediately affects hormone activity, symptoms like blood pressure and pulse and by thus, it affects Heart Rate Variability (HRV) (Hainsworth, 1995; Nickel and Nachreiner, 2003; Jonsson, 2007). Therefore, HRV can be considered as an indicator for physiological stress. Several studies show that Heart Rate Variability may be significantly affected by exposure to air pollution (Kurosawa et al., 2007) and thermal loads (Sawasaki et al., 2001; Bjor et al., 2007; Liu et al., 2008). However, as mentioned above, these studies pertain to a general measure of pollution as recorded by fixed monitoring stations.

A personally focused and ecologically valid study may be achieved by measuring individuals' exposure to environmental factors and autonomic responses while they perform their daily routines within their city. Such studies, including ours, apply frequency domain indices of HRV as indices of strain, anxiety and stress (Malik and Camm, 1993; Stein et al., 1994; Nickel and Nachreiner, 2003; Jonsson, 2007; Brosschot et al., 2007; Liu et al., 2008).

The aim of this research is to address HRV responses to four environmental factors, sampled with personally carried monitors. We hypothesized that: (1) An increased exposure to environmental factors through daily routine activities would result in an increased stress-related HRV index. (2) A cumulative effect of stress as measured by HRV would be evident along the day time. (3) A significant decrease in stress-related HRV function would be evident during the night as compared to day time.

2. Methodology

2.1. Methodological approach

The current research adopts an urban ecological approach pertaining to four domains: 1. The definition of the young 'Urbanite' socio-spatial lifestyle. 2. Intervening variables: time of day and season. 3. Exposure to independent set of environmental factors: noise, CO, thermal load and social stress. 4. Heart Rate Variability (HRV) as the dependent variable results of all above (Fig. 1).

2.1.1. The participants

36 young, healthy, non-medicated people between the ages of 23 and 40 residing in Tel Aviv-Jaffa (14 female and 22 males) participated in the study. Three of the participants were smokers, who avoided smoking during the days of the experiment. None of the participants used alcohol or any other substances.

The participants were instructed to follow a pre-determined route covering a few sites typical to young 'urbanites' in Tel-Aviv-Jaffa. The course of the route crossed the city from north to south and back. The route included indoor stations like shopping malls, the university grounds, restaurants and coffee shops, a pub, a night club and the participants' private homes in the metropolitan area of Tel Aviv-Jaffa. Outdoor stations along the route included a walk in open main and side streets and markets, a short visit in a park and a ride as passengers in public busses and private cars (Schnell et al., 2008). Each experiment was performed for two sequential days in groups of six participants, twice in the winter, twice in the summer, once in the spring and once in the autumn.

The participants stayed in a stable state for ten minutes in the middle of the time interval, of the 30–45 min allocated for their visit to each of the stations and in the middle of the route in between sequential stations producing, by thus about 20 measurements per day per participant. The data pertaining to HRV and subjective social stress (SSS) obtained in these intervals were used for analysis.

2.1.2. Exposure to independent set of environmental factors

In order to evaluate the exposure to independent set of environmental factors three methods were used: In situ measurements, calculations and a questionnaire.

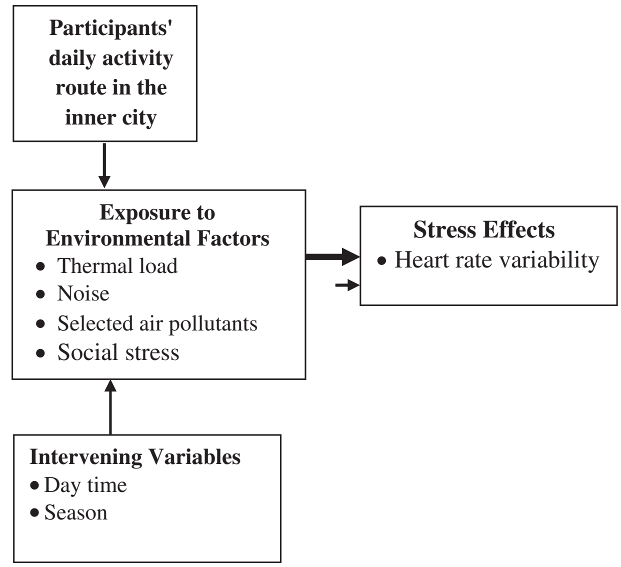

Fig. 1. The research framework.

The in situ measurements included two of the four independent variables – noise and CO which were continuously measured. CO Levels were measured and recorded using the portable monitor Drager Pac III sensor once every 60 s throughout the experiment. The instruments were calibrated both with 25 ppm CO calibration gas and fresh air before each study, and compared to CO data collected by one of the monitoring stations of the Israel Ministry for Protection of the Environment. The correlation coefficient (R) was determined to be 0.79, with the Pac III being more sensitive to immediate changes.

Noise measurements were recorded with a Quest pro DL dosimeter ranging from 40 to 110 dB, with resolution of 0.1 dB. The noise sensors were calibrated before each study using a QC-10 calibrator (114 dB, 1000 Hz). We measured the average noise level per minute over the run time.

Climatic variables of temperature and relative humidity were continuously measured by Fourier Microlog with a resolution of 0.5 °c and accuracy of ±0.6 °c. Relative humidity was measured with resolution of 0.5% and accuracy of ±3%). Radiant temperature and cloud cover were taken from the Israeli Meteorological Service and calculated according to the sun exposure of the subjects. Wind velocity was taken from the monitoring station of the Israeli Ministry of Environmental Protection, located within the Tel Aviv urban area.

On the base of these climatic variables thermal sensation were calculated. The Physiological Equivalent Temperature (PET) index was used to evaluate thermal load (Höppe, 1999) since it is the most commonly applied index for evaluation of human thermal perception, which has been tested by questionnaire survey in many field studies (Gulyas et al., 2006; Johansson and Emmanuel, 2006; Matzarakis et al., 2007; Thorsson et al., 2007; Cohen et al., 2013).

The PET was calculated using the PC modeling program RayMan (Matzarakis et al., 2007) developed according to Guideline 3787 of the German Engineering Society (VDI, 1998). According to the model, the calculation of thermal sensation requires the input of the following constants: body surface area was standardized to 1.9 m^2, which represents a human with a height of 1.75 m and a body weight of 75 kg (Höppe, 1984); the metabolic rate (Met) was fixed at an average value of 80 W/m^2 for a standing person; the insulation factor of clothing (Icl) was standardized to 0.9 for light summer clothing (Jendritzky et al., 1990).

The SSS was studied by asking participants to document their sense of comfort or stress stemming from the presence of other people in their close vicinities on a ten-point visual analog scale (VAS).

2.1.3. Heart Rate Variability (HRV)

HRV was recorded with a Polar 810i monitor for the 36 h of each experiment. The RR signal was converted to heart rate, linearly interpolated and graphed in regular intervals of 0.5 s (2 Hz). In this way, 256 segment signals, at a steady state condition, were obtained and multiplied by a Henning window. For each interval of activity, two to three segments were analyzed. We applied frequency domain analysis to evaluate HRV. Two different frequencies were analyzed in addition to total power: high-frequency power (HF) (0.15–0.4 Hz) and low-frequency power (LF) (0.04–0.15 Hz). According to the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, the HF domain represents vagally mediated respiratory variations, whereas the LF domain represents predominantly sympathetic activity (Hainsworth, 1995). In order to emphasize the controlled and balanced behavior of the two branches of the autonomic nervous system, LF and HF were estimated in normalized units and the LF to HF ratio was calculated as a measure of autonomic balance LF/HF (See also Wang et al., 2005).