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The timeline of blood pressure changes and hemodynamic responses during an experimental noise exposure

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ABSTRACT

Background: Noise exposure increases blood pressure and peripheral vascular resistance in both genders in an experimental setting, as previously reported by the authors.
Objectives: The aim of this re-analysis was to present the minute-by-minute timeline of blood pressure changes and hemodynamic events provoked by traffic noise in the young and healthy adults.
Methods: The experiment consisted of three 10-min phases: rest in quiet conditions before noise (Leq = 40 dBA), exposure to recorded road-traffic noise (Leq = 89 dBA), and rest in quiet conditions after noise (Leq = 40 dBA). Participants' blood pressure, heart rate, and hemodynamic parameters (cardiac index and total peripheral resistance index) were concurrently measured with a thoracic bioimpedance device. The raw beat-to-beat data were collected from 112 participants, i.e., 82 women and 30 men, aged 19–32 years. The timeline of events was created by splitting each experimental phase into ten one-minute intervals (30 intervals in total). Four statistical models were fitted to answer the six study questions what is happening from one minute to another during the experiment.
Results: Blood pressure decreased during quiet phase before noise, increased in the first minute of noise exposure and then decreased gradually toward the end of noise exposure, and continued to decline to baseline values after noise exposure. The cardiac index showed a gradual decrease throughout the experiment, whereas total vascular resistance increased steadily during and after noise exposure.
Conclusions: The timeline of events in this 30-min experiment provides insight into the hemodynamic processes underlying the changes of blood pressure before, during and after noise exposure.

1. Introduction

Human reactions to noise in an experimental setting were a focal point of research for a long time. The biochemical, endocrine and cardiovascular changes (Ising et al., 1999; Ising and Michalak, 2004) provoked by short-term exposures to loud sounds in the laboratory helped researchers understand noise as an environmental stressor, explore the physiological processes underlying these reactions, and explain the effects of noise on one's mental health, annoyance, sleep, and cardiovascular system (Babisch, 2002). In a similar attempt to comprehend blood pressure changes caused by noise, a team of researchers conducted an extensive experimental study in Belgrade in 2012, when young healthy volunteers with normal blood pressure were exposed to recorded road-traffic noise for ten minutes and had their cardiovascular and hemodynamic parameters monitored before, during and after noise exposure. The experiment showed a significant increase in blood pressure and peripheral vascular resistance and a decrease in heart flow and blood volume during noise exposure in comparison to quiet conditions before or after noise (Paunovic et al., 2011; Paunović et al., 2013, 2014).

Encouraged by these findings the team wanted to take a closer look at the chronological course of the events happening throughout the experiment. We were not satisfied with reporting only the average values of the investigated cardiovascular parameters before, during and after noise exposure, because they provided no insight into the timeline of the events during the experiment. We were, in short, wondering when the changes of blood pressure started, how long they lasted, and when they eventually ended. We expected not only to observe the physiological processes in every minute of the experiment, but also to analyze them in relation to the preceding minutes and between the

Abbreviations: Leq, equivalent noise level; dBA, A-weighted decibel unit

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experimental phases, hoping to understand blood pressure changes and hemodynamic responses in short-term stressful events. We decided to perform a new analysis of the existing data, aiming to assess the minute-by-minute timeline of the changes in blood pressure and other cardiovascular and hemodynamic parameters provoked by recorded traffic noise in the young and healthy adults.

2. Materials and methods

The experimental study was performed in 2012 in the collaboration between the Institute of Hygiene and Medical Ecology, Faculty of Medicine, and the Multidisciplinary Center for the Diagnostics and Treatment of Arterial Hypertension, Clinical Center of Serbia. The study design is described in details previously (Paunovic et al., 2011; Paunović et al., 2013, 2014). In short, 132 young healthy volunteers, i.e., medical students and young medical doctors (aged 19–32 years), signed an informed consent form to participate in the experiment in which they would be exposed to loud recorded road-traffic noise for ten minutes and would concurrently have their cardiovascular and hemodynamic parameters monitored by a non-invasive method. The expected results of the experiment were not discussed with the participants before, during, or after the testing procedure, to prevent from the possible anticipation-bias. The study was approved by the Ethics Committee of the Clinical Center of Serbia in 2009.

Before enrolling the study, all participants underwent a medical examination and had their weight and height measured in light clothes and barefoot. Body mass index (BMI) was calculated as body weight (in kilograms) divided by squared body height (in meters). At this point, some volunteers were excluded from the study due to the presence of diabetes (n = 1), kidney diseases (n = 1), obesity (n = 3), hypertension (n = 5), and arrhythmia (n = 2) (Paunović et al., 2014). Participants fulfilled a questionnaire containing socio-demographic data (age, gender), smoking habits (non-smoker / current smoker / ex-smoker), regular engagement in physical activity for at least 30 min most days per week (yes / no), and some eating habits, such as daily use of coffee (yes / no), and daily addition of salt to food during meals (yes / no) (Paunović et al., 2014). None of the participants followed any specific dietary regimen.

2.1. Experimental procedure

All eligible participants were asked to avoid smoking, drinking coffee or intensive physical activity for at least two hours before the testing procedure. The experimental procedure consisted of three phases. At the beginning before noise exposure, participants rested for 10 min in quiet conditions (Leq = 40 dBA). In the second phase, participants listened to the recorded road-traffic noise (Leq = 89 dBA) for 10 min. After noise exposure, participants remained lying for another 10 min in quiet conditions (Leq = 40 dBA). Two loudspeakers were placed at both sides of a subject's head at 30 cm distance. Equivalent noise levels were measured with Hand Held Noise Level Analyzer Type 2250 'Brüel & Kjær' at the level of participants' ear. Participants were lying on their back with their arms and legs outstretched and with the thoracic electrical bioimpedance device connected during the whole course of the experiment (Paunović et al., 2014).

Thoracic electrical bioimpedance device (Task Force® Monitor, CNSystems Medizintechnik AG, Graz, Austria) consists of impedance cardiography electrodes (ICG), electrocardiography electrodes (ECG) and two sets of cuffs for blood pressure measurement. Impedance cardiography (ICG) electrodes measure the change in thorax impedance during the flow of the alternating current through the thorax. Subsequently, the impedance change during a cardiac cycle serves to estimate thoracic fluid content (the electrical conductivity of the chest cavity, determined by fluids in the thorax, 1/kOhm), and to compute several cardiac parameters, such as: stroke volume (the amount of pumped blood during each systole, ml), systolic index (indicator of pumped blood volume, ml/m^2; calculated as stroke volume normalized for body surface area), cardiac output (minute volume of heart, l/min), and cardiac index (indicator of global heart flow, l/(min*m^2); calculated as cardiac output normalized for body surface area). The validity of impedance cardiography to measure stroke volume and cardiac output in healthy adults was confirmed in comparison to other standard methods (direct Fick method, dye dilution, carbon-dioxide rebreathing) (Woltjer et al., 1997).

In addition, the thoracic electrical bioimpedance device measures heart rate (beat/min) and blood pressure (mmHg) in two ways: by oscillometry (a cuff is placed on patient's left forearm) and during every heart beat (continuous beat-to-beat measurement on patient's right hand; two ring cuffs are placed on person's index finger and middle finger). Mean arterial pressure (mmHg) is calculated as a sum of systolic pressure and doubled diastolic pressure, divided by three. The device performs the oscillometric blood pressure measurements every three minutes, making such recording inapplicable for the timeline analysis; they were, thus, excluded from the presented study.

Finally, based on previous cardiac parameters, heart rate and blood pressure, the device calculates total peripheral resistance (the resistance of all peripheral vasculature in the systemic circulation, dyne*s/cm^5), as well as total peripheral resistance index (indicator of systemic vascular resistance, dyne*s*m^2/cm^5; calculated as total peripheral resistance normalized for body surface area). Body surface area is calculated from the Mosteller formula (Mosteller, 1987) as a square root of a product of body weight (in kilograms) and body height (in centimeters) divided by 3600. The state of blood inside the vascular system, i.e., hemodynamics is determined by mean arterial pressure, cardiac output and peripheral vascular resistance (Paunović et al., 2014).

Once the experiment was completed, data were exported from the thoracic electrical bioimpedance device, assembled into a database and analyzed for outliers. At this stage, data from 10 participants were excluded due to the errors in the recordings. Later, a detailed data analysis revealed errors in the measurement of three participants and missing data in five participants, who were thus excluded from the timeline analysis. Finally, the minute-by-minute timeline of all the events during the experiment was created from the data collected from 112 participants, i.e., 82 women and 30 men.

Given the limited space, we were not able to describe all the investigated cardiovascular parameters; we have decided to report the timeline of blood pressure (obtained from the continuous beat-to-beat measurement), and its hemodynamic constituents, i.e., peripheral vascular resistance, cardiac output, and heart rate.

2.2. Timeline analysis

In order to perform the timeline analysis, all three experimental phases that lasted for ten minutes were divided into ten one-minute intervals, and the average values of all the investigated parameters were calculated from raw beat-to-beat data. This procedure created a total of thirty average values per investigated parameter per person. Once all individual data were aggregated, the following four comparisons were made: 1) the values obtained at a given minute were compared to the values obtained at the preceding minute (Model 1; 29 pairs of values in total); 2) the values obtained at a given minute were compared to the values obtained at the first minute of the same phase (Model 2; 9 pairs of values per phase, i.e., 27 pairs of values in total); 3) the values obtained at every minute of noise exposure and quiet phase after noise were compared to the values obtained at the last minute of quiet phase before noise (Model 3; 10 pairs of values per phase, i.e., 20 pairs of values in total); and 4) the values obtained at every minute of quiet phase after noise were compared to the values obtained at the last minute of noise exposure (Model 4; 10 pairs of values in total).

These models were incorporated into the following study questions: