BEHAVIOUR OF HUMAN HEMODYNAMICS UNDER MICROGRAVITY – A PROPOSAL FOR THE 7th GERMAN PARABOLIC FLIGHT CAMPAIGN

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Summary All astronauts often feel uncomfortable during first encounter microgravity because of fluid shifts from the lower extremities to the head caused by weightlessness. Parabolic flights offer a great possibility for research of this phenomenon under "zero gravity". With a combination of the optoelectronic sensor concepts PPG and PPGI and an ultrasound device it should be possible to measure all relevant parameters for description and further explanation of rapid fluid shifts along the body axis in humans during parabolic flights. A research team of the RWTH Aachen University and the Charité University Berlin will participate in the 7th German Parabolic Flight Campaign in September 2005 and perform the experiments under micro gravitation. A combination of used non-invasive strategies will reveal new insights into the human hemodynamics under microgravity conditions.
The optoelectronic part of this interdisciplinary research experiment, details from the measuring setup, data collecting and post processing will be discussed.

Abstrakt Sdělení představuje koncept biofyzikálního experimentu, zaměřeného na detekci a analýzu rychlých změn tělesných tekutin podel osy člověka při mikrogravitačních podmínkách (~ 10^{-2} g) během opakovaných parabolických letů, a to pomocí optoelektronických a ultrazvukových senzorů. Experiment je plánován v interdisziplinární spolupupráci vědeckých univerzitních týmů v Berlíně a Cáchách v rámci 7. německé DLR kampaně a bude probíhat v září 2005 v Bordeau.

1. INTRODUCTION

All astronauts travelling into space complain about fluid shifts from the lower legs to the head. This phenomenon is known as "space motion sickness", "puffy faces" or "bird legs" (figure 1). In the past it was very difficult to study the amount and the dynamics of these fluid shifts. On earlier space missions research teams were able to proof these fluid shifts in the superficial tissues, but there was no ability to quantify these shifts and their dynamics. The fluid shifts during space flight can be noticed because under zero gravity in the aerospace the human body is exposed to a completely other stress than on earth.

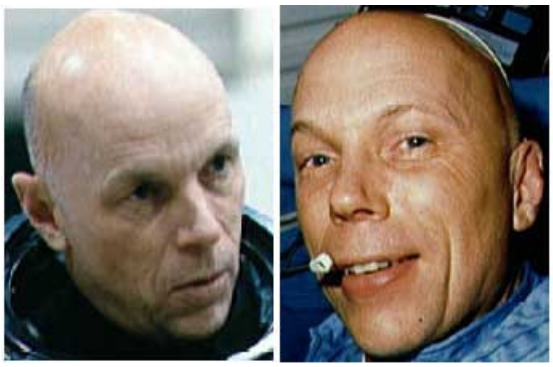

Fig. 1. Astronaut Story Musgrave, Space Shuttle Challenger, Mission STS6, April 1983, on Earth (left) and in orbit (right) [1]. The puffiness around his eyes and cheeks caused by microgravity can be clearly seen.

Within the scope of the evolution humans developed from quadrupeds to bipeds. The price for this privilege to stand upright on just two feet is that more than 80% of the human blood is normally distributed in the lower extremities as a result of the Earth's gravity. Because of the large amount of blood in the legs many humans suffer from venous diseases. Humans can hide themselves from many environmental influences, but not from the Earth's gravity except they travel to space. The distribution of the blood volume throughout the human body and physiological blood pressure values while standing on the Earth are shown in figures 2 and 3.

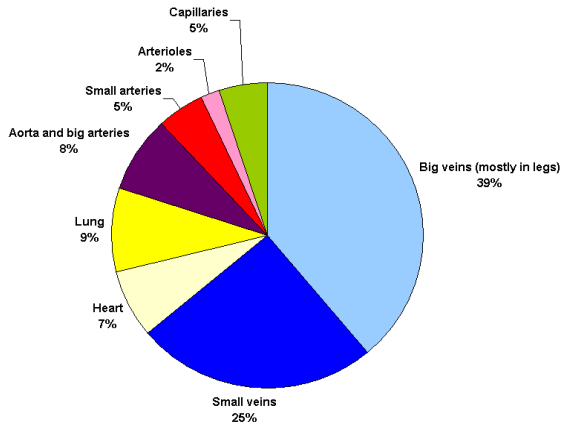

Fig. 2. Distribution of blood volume for the different parts of the human vascular system [2].

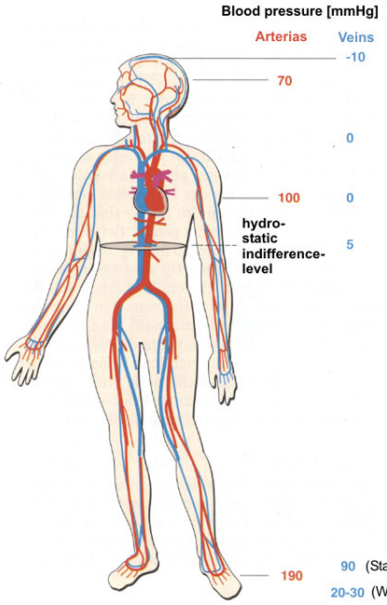

Fig. 3. Blood pressures in the arterial and venous system of a standing human under Earth's gravity [2].

2. MICROGRAVITY CONDITIONS DURING PARABOLIC FLIGHT MANOEUVRE AND EXPERIMENTAL BACKGROUND

Within the framework of the German government long term program "Research under space conditions" our experiment will be performed during repeated parabolic flight manoeuvre, also called "Zero G" (figure 4). The experiments are planned for the 7th German Parabolic Flight Campaign in September 2005 and are coordinated from DLR in Bonn (Deutsches Zentrum für Luft- und Raumfahrt e.V.). During four flights in four days 120 parabolic phases will be performed with a specially prepared aircraft Airbus A 300. From a steady horizontal flight, the aircraft gradually pulls up its nose and starts climbing at an angle of approximately 45 degrees. This "injection" phase takes about 20 seconds, during which the aircraft experiences an acceleration of around 1.8 times the gravity level at ground, i.e. 1.8 g. The engine thrust is then reduced to the minimum required to compensate for air-drag, and the aircraft follows a free-fall ballistic trajectory, i.e. a parabola, taking approximately 20 seconds, during which weightlessness is achieved. At the end of this period, the aircraft must pull out of the parabolic arc, a maneuver which gives rise to another 20 second period of 1.8 g on the aircraft, after which it returns to normal level flight attitude. Thus, the whole parabolic phase takes 1 min. These maneuvers are flown repeatedly, with a period of 3 minutes between the start of two consecutive parabolas, so that there is a 2 minute "rest" period at 1g. After parabolas 10 and 20 however, the rest interval is increased to 6 minutes. During one flight 30 parabolas will be performed.

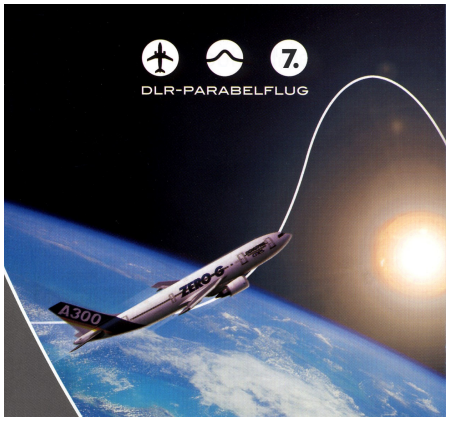

Fig. 4. Airbus A 300 performing a parabolic flight.

3. ASSESSMENT OF HUMAN HEMODYNAMICS UNDER SPACE CONDITIONS USING OPTOLECTRONIC SENSORS

3.1 Fundamentals of classical Photoplethysmography (PPG)

The PPG technique is a well known method for non-invasive investigations of the dermal blood perfusion. It is based originally on different absorption and scattering coefficients of bloodless skin and blood-filled vessels for photons of infrared light [3-5].

The simplest reflection mode PPG sensor consists of an LED and a photo detector, placed in a small plastic housing (figure 5). The distance between light emitter and light detector is about 6 mm. The sensor is applied to the skin by means of a double faced adhesive ring. Four ventilation channels in the frond allow the free circulation of air beneath the sensor and even allow long time application and measurement under space conditions.

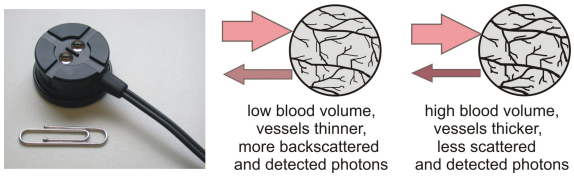

Fig. 5. PPG sensor and schematic visualization of the correlation between the PPG signal and the blood volume changes in the illuminated vascular network under the sensor [5].

The relative sensitivity of effective measurement depth of the optoelectronic sensors can be adjusted by variation of distance x between light emitter E and light detector D and axis alignment of both components as well as the beam angle α of the

opening (numerical aperture NA). For the classical PPG sensor shown in figure 5 (x=6mm, α=+/-5°, NA=0.087) lies the range of measuring depth (decrease 1/e of maximum sensitivity) between 0.1 and 3.2mm, maximum sensitivity is in 1mm skin depth and transilluminated tissue volume approx. 120 mm^3. The intensity distribution of in the tissue injected photons can be calculated by means of Monte Carlo simulation [7]. One typical example is shown in figure 6. The horizontal coordinates x and y run from -7mm to 7mm, the source is centred at (0,0). The z-axis depicts the normalized light intensity in skin tissue. The scattering causes a widening of the light rays. At the same time, the maximum intensity (I(r=0)) is reduced from 43% in 2.4mm to 19% in 3.6mm depth, relative to the skin surface values.

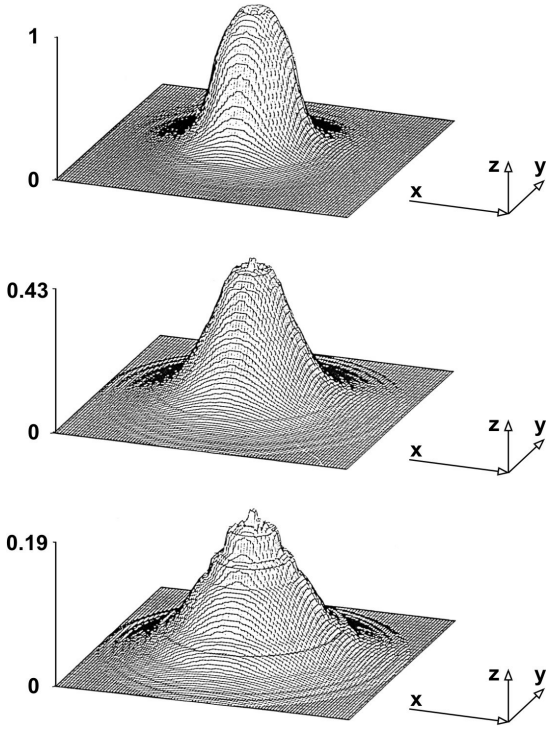

Fig. 6. Simulation of photon distribution in tissue under light emitting point of classical PPG sensor in the skin depths of 1.2mm (top), 2.4mm (middle) and 3.6mm (bottom).

A typical light intensity distribution of the measuring rays in the tissue under the PPG sensor is shown in figure 7. The curves of constant light intensity determine the decrease down to 10%, 1%, 0.1% and 0.01% of maximum light intensity. In this case, about 90% of the backscattered and detected signal comes from the bloodless tissue (T), 10% from venous blood volume (V) and about 0.1% from arterial blood volume (A). This leads to a sum signal consisting of a large signal offset, a slowly changing venous portion (quasi DC signal) and a pulsating arterial signal (AC signal).

Since the development of this method in the seventies, PPG has become an approved technology nowadays, which is used by clinicians and practitioners worldwide under "terrestrial" conditions. The biggest advantages of PPG are a simple and flexible setup, low cost for equipment and measurement and the possibility to measure functional data of the venous and arterial system.

3.2 Synthesis of the PPG signal: venous and arterial part

Furthermore, a newer multi sensor version of the classical PPG, which can measure the DC and the AC part of the signal (figure 8) at the same time, will be installed. Using the data of this system it is possible to reconstruct the complete PPG signal of the observed areas. This is very important, because in the past most PPG-measurement-setups were only able to measure the AC-part of the PPG-signal. The AC signal contains basically only the arterial part of the blood volume pulse. The information about the changes caused by bigger fluid shifts is, however, also included in the venous and static part of the signal. The ratio of AC to DC components in the PPG signal gives the normalized PPG% value for the photoplethysmogram amplitude.

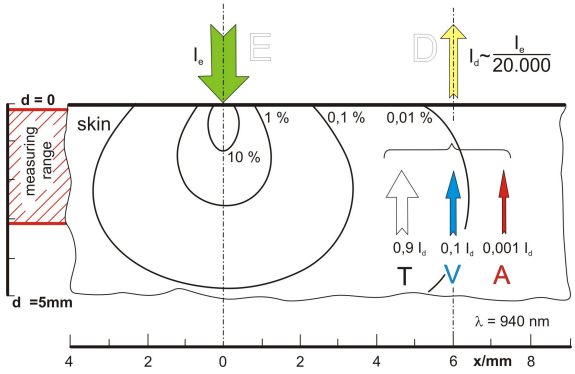

Fig. 7. Schematic cut through the biological tissue with curves of constant light intensity. A distance of x=6mm between emitter E and detector D results in a mean signal loss of approximately 43dB [5].

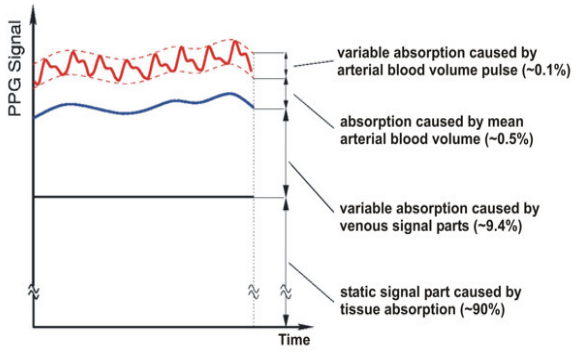

Fig. 8. Different parts of a PPI signal [6].

3.3 Photoplethysmography Imaging (PPGI)

In spite of all advantages the classical PPG has two disadvantages. The first problem is the need to fix the sensor on the tissue. Thus, it is not possible to measure in wounds. The second problem is that it is possible to measure only one or a few single spots due to the limited number of sensors. The photoplethysmography imaging (PPGI) system meets both requirements. Instead of one single LED a kind of LED floodlight is used to illuminate a bigger area. An extremely sensitive & high resolution scientific camera is used as a detector for the back scattered photons [8-10]. A basic PPGI setup is shown in figure 9 and a realized system for first clinical tests in figure 10.

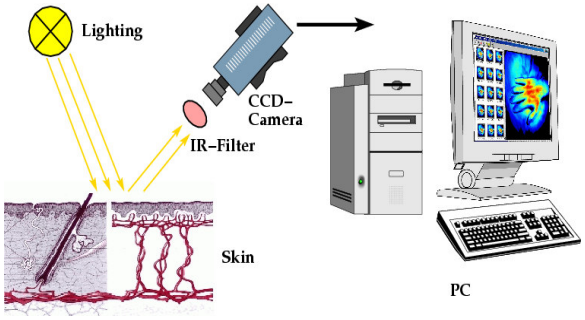

Fig. 9. Basic PPGI setup. Using high resolution CCD-sensor, spatial resolved hemodynamic studies can be performed [9].

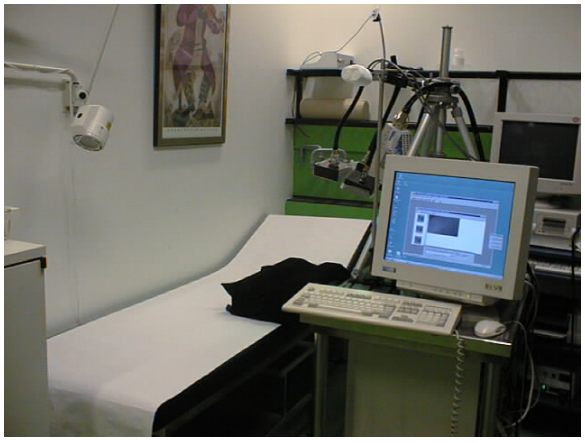

Fig. 10. PPGI setup for measurement of a subject in supine position [10].

4. EXPERIMENT

The "parabonauts" will be lying in supine position. During each flight, two subjects will be investigated (change of position after 15 parabolas by two experimenters. One experimenter is necessary to perform the ultrasound scans at two marked points of the body (forehead and tibia), the other experimenter is necessary to (re-)focus the PPGI camera on the subject's forehead and to start/stop the image series. The induced changes during the parabolic arcs under microgravity (~ 10^{-2} g) and hypergravity (+1.8 g) conditions will be assessed. The Airbus A 300 provides an experiment lab with the area of 20 x 4.9m (figure 11) for 12 different experiments of the 7. DLR mission.

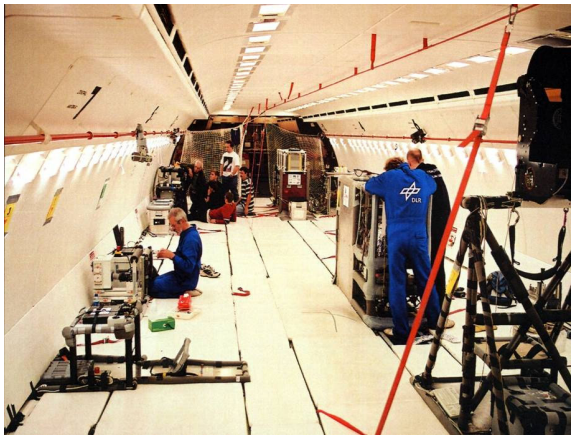

Fig. 11. Experiment area in the centre of the mission airplane A 300. (Foto: Dr. U. Friedrichs, DLR).

5. PRELIMINARY RESULTS: RAPID BLOOD VOLUME SHIFTS DURING TILL TEST AS A „SIMULATOR OF MICROGRAVITY"

In preparation for our microgravity experiment measurements using an electrically controlled tilt chair have been performed. The aim of this preliminary test was to assess the influence of the hydrostatic blood pressure changes in dermal hemodynamics. During the passive tilt test the subject was moved rapidly from sitting position to horizontal position (figure 12). The PPG sensor was attached on the inner side of the lower leg, nearly 8 cm above the ankle.

Following this maneuvre the peripheral venous blood pressure in the sensor level decreased about 45 mmHg. The recorded PPG signals clearly reveal blood volume shifts from the lower extremity immediately after the changes of body position. Under reduction of hydrostatic pressure the photoplethysmogram rises in a few seconds following a physiological venous outflow from the extremity in the central and upper body regions. After the repositioning of the subject to vertical position the increase of the PPG signal visualises the refilling of the leg which is influenced by physiological venodynamics only through the arterial inflow. These results allow us to presume that the rapid fluid shifts in the human body can be detected using optoelectronical sensors also during short microgravity phases as planned.

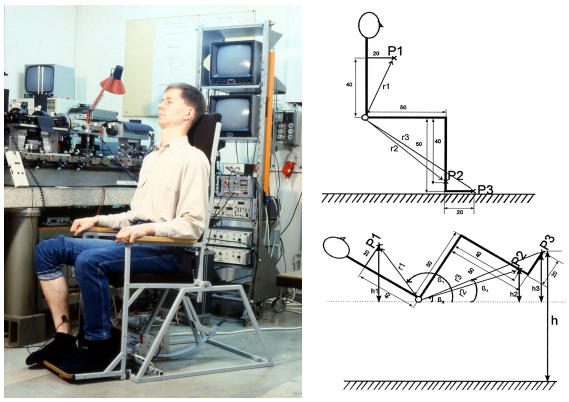

Fig. 12. Passive tilt test in IHF/RWTH lab.

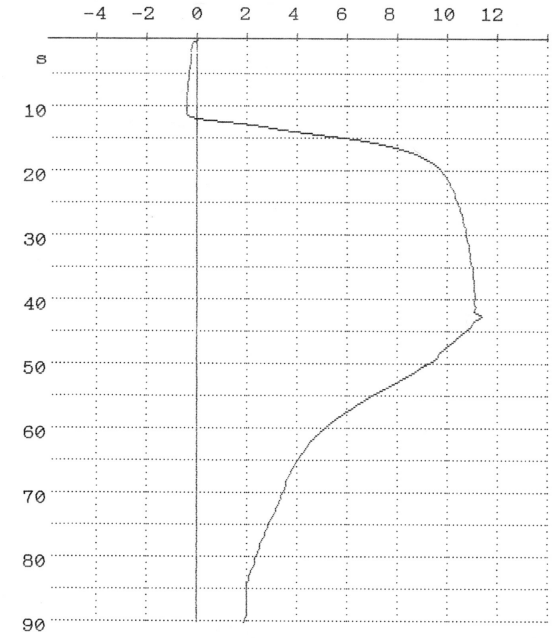

Fig. 13. PPG registration of rapid blood volume changes during motorized tilt test. The vertical axis visualises the signal amplitude normalised in PPG% (changes of venous signal part in relation to the initial venous signal before tilt test) versus time.

6. CONCLUSION

It is intended to demonstrate that during a parabolic flight rapid fluid shifts into the superficial tissue occur. With the help of the optoelectronic sensors it should be possible to access the filling and refilling of the superficial venous and arterial vascular bed. In addition, information about rhythmic patterns in dermal perfusion can be evaluated. Furthermore, ultrasound methods will be applied to quantify the fluid shifts. Using our multi sensor concept it should be possible to reveal new insights in the dynamics of rapid fluid shifts. The optoelectronic parts of the experiments are the tasks of the Aachen investigator group, while the ultrasound measurements will be performed by the team members from the Centre for Space Medicine, Charité Berlin.

During the flight only the raw data will be recorded. The analysis will be performed afterwards.

Acknowledgement

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