PHYSIOLOGICAL RESPONSES DURING EXAMINATION IN RAPID LBNP EXPOSURE

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Abstract: An LBNP (Lower body negative pressure) examination technique is applied in our case as one of the possibilities for preliminary indirect individual estimation of the pilot's positive gravitational acceleration (+Gz) tolerance. It partly replaces demanding and expensive examinations in a human centrifuge. LBNP exposition is also utilized as a method of drill in anti-g manoeuvres. LBNP examinations allow evaluating entirely the orthostatic part of the actual cardiovascular response as the basic part of the complex resistance to overloading. Although the LBNP load represents a principally different load than +Gz overloading, possibilities of the prediction of the low level of +Gz tolerance using an LBNP method were proved. The LBNP examination method was developed for the applicants' pre-selection with low level of +Gz tolerance.

LBNP EXAMINATION METHOD

An LBNP examination method is mainly used as a load test within special diagnostics and furthermore as a fitness prevention at individuals who are for long time exposed to low lever of the orthostatic load, such as for recondition prophylaxis in conditions of the long-term microgravity during space flights or after space flights [5, 11, 13]. In these cases a long-run impact of negative pressure low values up to minus 20 mmHg is applied. On the contrary in our case a pilot is exposed to negative pressure high values, however for short time [2, 6, 12, 14, 15].

Current LBNP examinations are accomplished with one-step exposure at the negative pressure level of minus 70 mmHg with achievement of this value in one second. It means the negative pressure onset is quick and therefore we speak about a rapid LBNP exposure. Pilots are examined in the sitting position with the possibility to tilt the chamber backward [7]. The LBNP device is shown in Figure 1. The negative pressure chamber is tightened in a position of the body waist by means of the elastic rubber cuff as it can be seen in Figure 2. Results of the test depend on exposure time duration. It is determined by subjective and objective tolerance and physiological data changes of the examined pilots. Objective LBNP stop criteria were assessed pursuant to statistical evaluation of blood pressure (BP) and heart rate (HR) behaviour. Negative pressure descent after the LBNP exposure ending is accomplished with a lower speed and with achievement of the zero negative pressure level in ten seconds. Training of both strain and breathing anti-g manoeuvres is a part of an LBNP examination method. Strain and breathing anti-g manoeuvres test is checked up closely before the collapse state.

Figure 1: View of the LBNP device

LBNP DEVICE

The developed device makes it possible to achieve minus 150 mmHg negative pressure within shorter time than one second. All operation modes are controlled by the Motorola microprocessor MC68HC916Y3 that collaborates with PC control software. The greatest attention is paid to the safety of operation because it concerns very demanding examinations when the total collapse of the examined subject might easily occur. It

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has on no account to break out any uncontrolled increase in negative pressure. Negative pressure regulation in the chamber is protected from the safety of operation point of view by a number of measures.

The control program will put a stop to exposure in the event of negative pressure overrun of more than minus 8 mmHg of its required value. In our described case this means minus 78 mmHg negative pressure value. With an exceptionally possible failure of the control program a control based on combinations of the program and circuit protection begins operating. The exposure is interrupted if negative pressure exceeds required level by minus 10 mmHg. The control program puts down required negative pressure value increased by minus 10 mmHg into a digital-to-analog converter (DAC) before an LBNP exposure. There is minus 80 mmHg in the given case.

Figure 2: Examination of the pilot in LBNP load, (The elastic rubber cuff can be seen in a position of the body waist)

The DAC output voltage is being compared with the electromanometer output voltage by the circuit comparator. The electromanometer output voltage corresponds to negative pressure level in the chamber of the device. This voltage must not exceed the pre-set DAC output voltage. If it happens, the emergency circuit will switch off the power supply of all input and output valves. At that moment all input valves will be closed and one output valve will remain open. The block diagram in Figure 3 shows an interconnection of all input and output valves. The output valve NO (normally open), which is a component part of the whole package of output valves, will connect the chamber with the atmosphere. During exposure it is all the time mains powered so its outlet is closed. All input valves connecting the LBNP chamber with a vacuum reservoir are NC pattern (normally closed), which means that they are open by a control signal. The electromechanical valve of the wide opening ensures permanent disconnection of the LBNP chamber from a vacuum reservoir when the LBNP device is out of operation. A guard circuit operation is independent of a control program. This guard circuit guarantees safety of operation with an exceptionally possible failure of the control program.

In the event of a possible electromanometer or DAC circuit's failure, the negative pressure switch takes over the guard control. This function is fully independent of software and hardware, both a microprocessor system and a PC. The exposure is finished if negative pressure overruns the pre-set maximal negative pressure level. This value is minus 90 mmHg for the schedule of the orthostatic tolerance testing. Respondent to any negative pressure error the power supply of all input and output valves is again switched off. The same situation will also turn up with an outage. In both cases all input valves are closed and one output valve remains open as explained above.

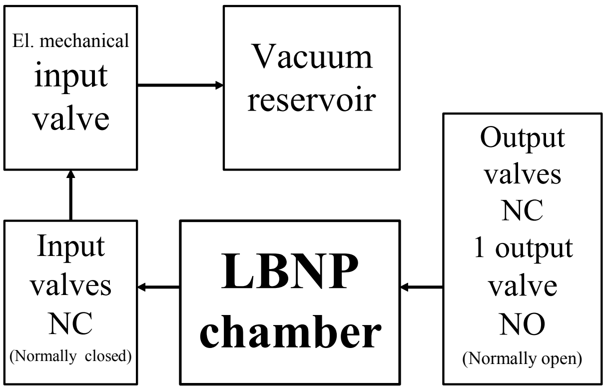

Figure 3: Block diagram of the interconnection of all input and output valves

The set of input valves consists of tree single digit valves with the wide outlet section, two valves with 6-bit configuration and one valve with 8-bit configuration. These valves have variable flow levels up to 64 or 256 flow levels with 8-bit configuration. Response times both in opening and in closing are less than a millisecond and are independent from the flow value. Valves with 6-bit configuration have greater flow than valves with 8-bit configuration. All input valves are normally closed type which means that they are closed in mode without power supply. The set of output valves

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consists of three single digit valves with the wide outlet section, one valve with 6-bit configuration and one valve with 8-bit configuration. One single digit valve is normally open type, the others are normally closed type. All applied valves represent the ideal solution for the flow control in a digital way (Pulse Code Modulation technique).

LBNP STOP CRITERIA

LBNP stop criteria have been stepwise experimentally elaborated. The exposure is interrupted in one of the following events:

- Heart rate excess over 170 pulses per minute.
- Heart rate drop by more than 20 pulses per minute (bradycardya beginning) within 20 seconds.
- Systolic blood pressure drop below 40% of its initial (in an instant just before the exposure) value.
- Pulse pressure (differential value between systolic and diastolic pressure) drop below 30% of its initial value.
- Systolic blood pressure drop below 50% of its initial value together with the heart rate drop by more than 20 pulses per minute within 20 seconds.
- Pulse pressure drop below 40% of its initial value together with the heart rate drop by more than 20 pulses per minute within 20 seconds.
- The decrease of systolic blood pressure value below 85 mmHg.
- The decrease of diastolic blood pressure value below 40 mmHg.

As indicated above the LBNP exposure will also have been finished in case of the following pilot's negative subjective feelings:

- Vision failure (unfocused vision, greyout, blackout).
- Negative vegetative symptoms (feeling of warmth in a head and in upper extremities, sweating, nausea, paresthesia).
- Loss of consciousness.

The LBNP device is equipped with a physiological acquisition system that evaluates in addition to the blood pressure and heart rate also ECG (three channels) and ear-photoplethysmogramm from both ears. The ear-photoplethysmogramm is used for assessment of eventual pilot's collapse state beginning as an additional parameter to the blood pressure. Physiological data record is synchronously eked out with negative pressure signal in the LBNP chamber. Pilots with a short exposure time duration under one minute belong to the substandard result group.

Blood pressure ranks among the essential physiological data measured during LBNP examinations. Blood pressure responds very sensitively to the LBNP load, which stands for a significant parameter reflecting the cardiovascular regulation level in the orthostatic load.

BLOOD PRESSURE MEASUREMENT

Physiological response of the organism during an LBNP examination is rapid, and therefore it proved to be advantageous to measure the continuous finger blood pressure by a Portapres device [1, 7, 10]. At this continuous measuring method finger pressure is not always close to arterial pressures measured more upstream, for example in the radial or brachial artery or in the aorta. A decrease in association between finger and more proximal pressures occurs in cases of strongly contracted arteries in the finger or upstream in the hand, in cases of Raynaud's phenomenon and in cases of proximal arterial lesions. This can be observed most notably in the pulse pressure and the wave shape. In younger normotensive subjects, the pulse pressure is usually enhanced, i.e. larger in the finger than in aorta or brachial artery. The more compliant the arteries of arm and hand are, the larger is the pulse amplification effect.

During an LBNP examination, however, we found out even more differences, especially greater pulse amplifying effect and the multiple occurrence of the higher absolute values of systolic and diastolic blood pressure in comparison with the blood pressure measurement in supine conditions. Even though there are various algorithms which allowed to reconstruct the true intrabrachial waveform shape [4], we focus on the evaluation of its relative changes.

VERIFICATION OF THE OBJECTIVE LBNP STOP CRITERIA

Objective offline verification if our decision to stop an exposure was faultless and not premature, systolic blood pressure changes, pulse pressure changes and heart rate changes were subsequently evaluated. It was experimentally found that these changes are decisive in an interval of 30 seconds after the exposure beginning till the moment immediately before a pre-collapse state. Statistical evaluation supported by an examination of 45 bodies. From the total group, 13 bodies were rated as people with an insufficient orthostatic tolerance. The following data were measured, evaluated and then comparison was made between both groups with sufficient and insufficient orthostatic tolerance:

- Average supine systolic blood pressure value in one minute interval immediately before an exposure.
- Average supine diastolic blood pressure value in one minute interval immediately before an exposure.
- Maximally achieved systolic blood pressure value in an interval of 30 seconds after the exposure beginning till its ending.
- Diastolic blood pressure value in an interval of 30 seconds after the exposure beginning till its ending in an instant of the maximal systolic blood pressure.
- Calculated pulse pressure value in an interval of 30 seconds after the exposure beginning till its ending in an instant of the maximal systolic blood pressure.

- Minimally achieved systolic blood pressure value in an interval of 30 seconds after the exposure beginning till its ending.
- Diastolic blood pressure value in an interval of 30 seconds after the exposure beginning till its ending in an instant of the minimal systolic blood pressure.
- Calculated pulse pressure value in an interval of 30 seconds after the exposure beginning till its ending in an instant of the minimal systolic blood pressure.
- Average supine heart rate value in one minute interval immediately before an exposure.
- Average heart rate value in an interval from 10 till 20 seconds after the exposure beginning.
- Average heart rate value in 10 seconds interval before the exposure ending or the anti-g manoeuvres beginning.

Statistical test of the comparison of maximal systolic blood pressure value and pulse pressure value relevant to this systolic blood pressure value between groups with sufficient and insufficient orthostatic tolerance confirms that the decision about the stop exposure was right. We are working at statistical evaluation with converted relative data referred to supine data. Statistical test objective proved that both groups are significantly different. At both parameters i. e. systolic and pulse pressures we sought the significance of differences between groups with sufficient and insufficient orthostatic tolerance by an appropriate statistical method.

Since in both of these groups an assumption of the normal distribution is not guaranteed, we could not use parametric methods and we had to select such nonparametric method that did not demand a definite distribution. A method for two independent stochastic selections was chosen, namely the Wilcoxon - White test.

The high statistical significance of differences was proved at both parameters systolic blood pressure and also pulse pressure. The high statistical significance of differences was also proved at the average heart rate value in 10 seconds interval before the exposure ending or the anti-g manoeuvres beginning.

LBNP ANTI-G MANOEUVRES

The strain manoeuvre has been drilled in consideration of the correct tension rehearsal of appropriate muscular groups. For the breathing manoeuvre it is important not only to cope with forced expiration technique with short vigorous inspiration but also to deal with the correct respiration frequency. After both separate elements are mastered, a complex drill of the anti-g manoeuvres technique follows. Co-ordination and correct fulfilment of all elements of the preventive manoeuvre are accentuated. A proper practical exercise of anti-g manoeuvres in an LBNP load is initiated in the exposure ending or in an instant of first markers of cardiovascular system regulation insufficiency. This means at least one of the monitored and evaluated parameters mentioned in the section LBNP stop criteria. An examining physician has to observe recovery of the ear-photoplethysmogramm signal and especially the instantaneous increase in blood pressure. At this moment an LBNP exposure is finalized. Negative pressure in an LBNP device chamber is slowly levelled with the ground. During negative pressure reduction an examined person finalizes the breathing manoeuvres but he is keeping the strain manoeuvre of lower extremities and an abdomen throughout the whole negative pressure descent.

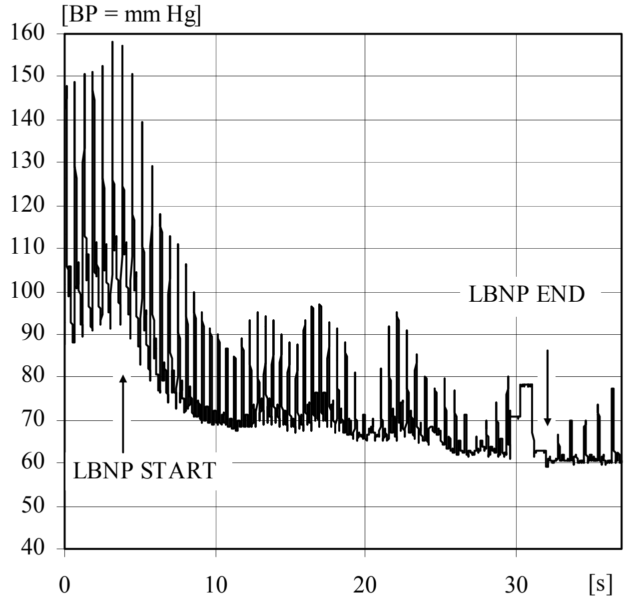

Figure 4: Continuous blood pressure (BP) behaviour during an LBNP load with a substandard result.

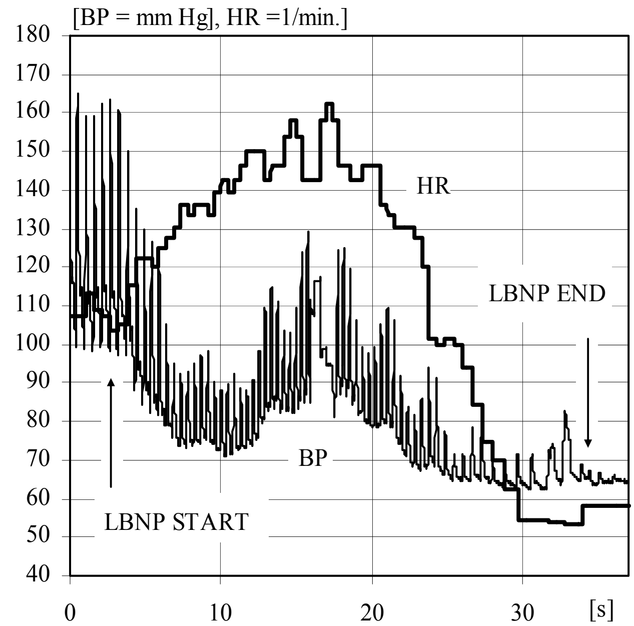

Figure 5: Blood pressure (BP) and Heart rate (HR) behaviour during an LBNP load with a substandard result.

Anti-g manoeuvres applications stand for regeneration or an increase of crucial ear-photoplethysmogramm drop. The systolic blood pressure has been increasing on average by 50% and the pulse pressure by 15% from an instant of the preventive manoeuvre until its completion. If a preventive manoeuvre is carried out well, its impact manifests an immediate rapid blood pressures increase. Again, if both breathing and strain component parts of the preventive manoeuvre are not carried out well, the total collapse of the examined subject might easily occur.

Well-timed and correct usage of anti-g manoeuvres towards an overloading in highly agile and powerful aircraft during flights is a fundamental assumption of the full exploitation of all aircraft properties. Demand for protection against gravitational acceleration with an anti-g manoeuvres use is also unavoidable in flights in less powerful aircraft. It concerns non-standard situations associated with +Gz acceleration such as an excessive or incorrect flying.

The effective strain muscle manoeuvres of lower extremities and an involvement of abdominal wall musculature decrease vein capacity so it reduces total blood volume injecting into a lower body, thus increasing venous blood into the right heart. The ear-photoplethysmogramm signal pulsation recover and the blood pressure improvement are evidential of the central nervous system blood flow revival.

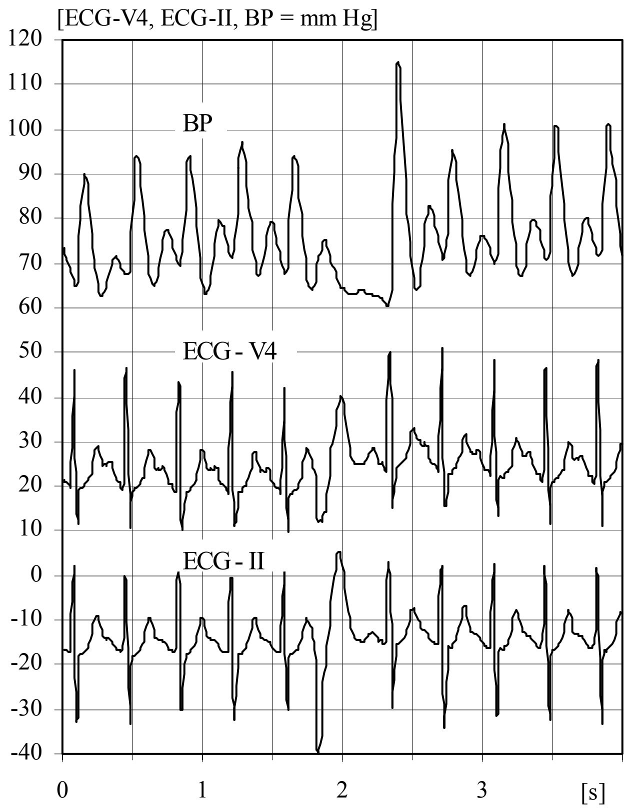

Figure 6: Occurrence of sporadic extrasystoles before LBNP load ending. But they particularly can be seen after LBNP load ending in an instant of blood volume regressive redistribution.

RESULTS

Blood pressure changes determine significant information about possible pilot's collapse state. The rapid blood pressure decrease comes into being very shortly after the LBNP exposure at the substandard result group (Figure 4). The rapid decrease of the systolic value is followed by pulse pressure decrease at the same time, too (Figure 5).

This demonstration is also an occurrence of the bad combination, when systolic blood pressure value and pulse pressure decrease are followed by rapid heart rate drop.

On the contrary, a slower decrease in both systolic and pulse pressure is characteristic of pilots with sufficient tolerance to the orthostatic load. Short-time systolic blood pressure rapid decrease can sometimes occur at the exposure onset at pilots incorporated to that group as well. Systolic blood pressure decrease has only short duration. Its value rises very soon as a manifestation of the effective compensatory response of the circulatory system.

We also registered occurrence of sporadic extrasystoles in some cases (Figure 6). Sporadic extrasystoles occur in the precollapse state beginning but particularly after LBNP load ending (in an instant of blood volume regressive redistribution - rebound phenomenon). Arrhythmia haemodynamic consequence is immediately seen in continuous blood pressure signal.

The typical example of the blood pressure and heart rate trends is in Figure 7.

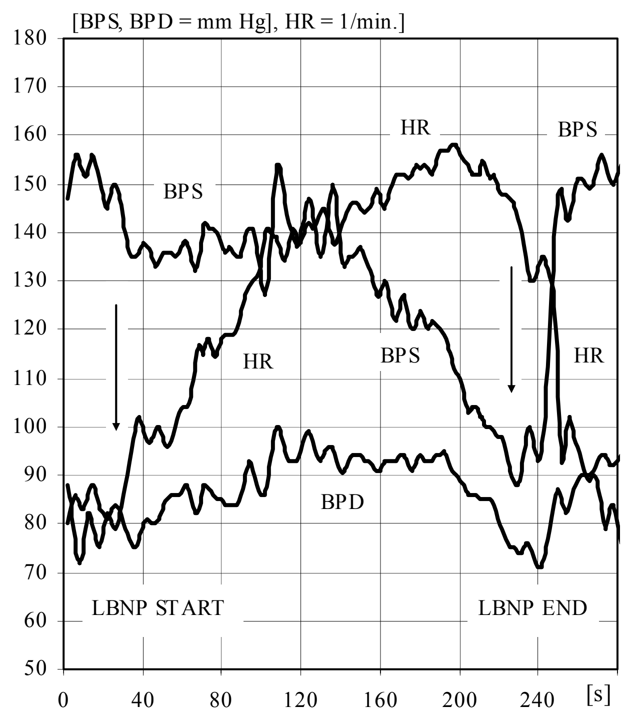

Figure 7: Systolic blood pressure (BPS), Diastolic blood pressure (BPD) and Heart rate (HR) behaviour during an LBNP load with a standard result.

The above suggests that LBNP exposition is also used as a method of training of strain and breathing anti-g manoeuvres. This exposition is an important training stage before the centrifuge training. The typical example of the blood pressure changes in an instant of beginning of anti-g manoeuvres is in Figure 8.

CONCLUSIONS

We compared pilot's physiological responses to the LBNP, flight and centrifuge load before now [3, 8, 9]. Physiological responses from the blood pressure and heart rate point of view are in an LBNP examination similar as in the plus 3.5 Gz in a human centrifuge and mostly correspond to the gravitational acceleration plus 4.5 Gz during flights in aircraft.

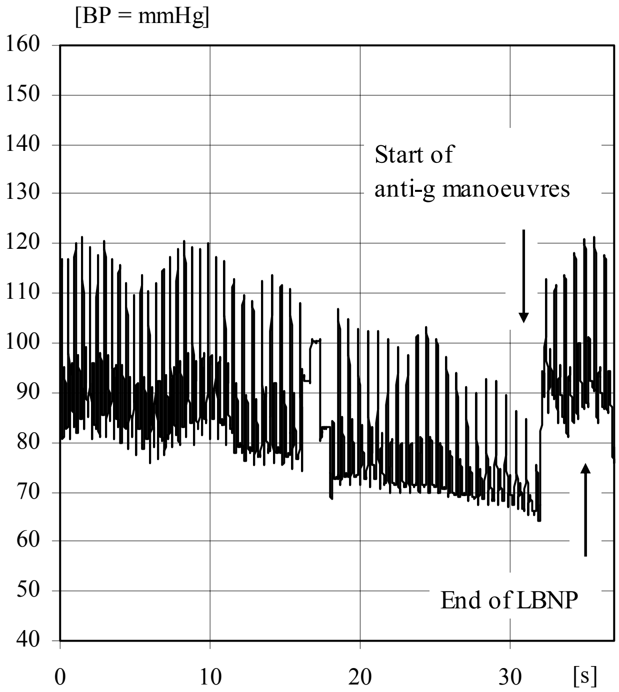

Figure 8: Blood pressure (BP) behaviour during an LBNP load with the standard result and with the exercise of anti-g manoeuvres.

The complex drill method of the anti-g manoeuvres technique was made out properly. It transparently demonstrates possible imperfections in the anti-g manoeuvres pursuance. Monitored data changes unambiguously validate the anti-g manoeuvres drill efficiency. Practical exercise of anti-g manoeuvres is a very important practice stage before pilots' testing in a human centrifuge.

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