Int J Biometeorol (1999) 43:31–37

ORIGINAL ARTICLE

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The effects of extra-low-frequency atmospheric pressure oscillations on human mental activity

Received: 22 August 1997/Revised: 3 December 1998/Accepted: 25 February 1999

Abstract Slight atmospheric pressure oscillations (APO) in the extra-low-frequency range below 0.1 Hz, which frequently occur naturally, can influence human mental activity. This phenomenon has been observed in experiments with a group of 12 healthy volunteers exposed to experimentally created APO with amplitudes 30–50 Pa in the frequency band 0.011–0.17 Hz. Exposure of the subjects to APO for 15–30 min caused significant changes in attention and short-term memory functions, performance rate, and mental processing flexibility. The character of the response depended on the APO frequency and coherence. Periodic APO promoted purposeful mental activity, accompanied by an increase in breath-holding duration and a slower heart rate. On the other hand, quasi-chaotic APO, similar to the natural perturbations of atmospheric pressure, disrupted mental activity. These observations suggest that APO could be partly responsible for meteorosensitivity in humans.

Key words Atmospheric pressure · Extra-low-frequency oscillations · Psycho-physiological response · Mental work efficiency

Introduction

Negative reactions of humans to weather changes are widely known to correlate with variations in atmospheric pressure. The human body is likely to be sensitive to the rate of pressure variation, d*p*/d*t*. According to various sources, the critical value of d*p*/d*t*, above which a response can be observed, is 5–10 hPa per day (Kolosova and Mindlina 1987; Madjidov et al. 1991; Novikov et al. 1992; Waehrens 1981) or 2–4 hPa in 3 h (Shtal et al. 1981). Much higher d*p*/d*t* values (up to 5–10 hPa per hour) frequently occur during stormy weather, which is usually accompanied by a considerable increase in a number of acute illnesses.

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Nevertheless, the traditional approach to atmospheric pressure as a factor influencing human health seems oversimplified. In most cases, barometer readings are only taken at certain times each day. As a result, only long-term pressure variations with oscillation periods exceeding a few hours can be observed. Meanwhile, a sensitive microbarograph (that is, a barometer with an electronic transducer and recorder) can measure more rapid **atmospheric pressure perturbations (APP)** over a wide range of intervals from fractions of a second to a few hours. Correspondingly, the frequencies measured mainly belong to the extra-low-frequency range 10^{-4}–1 Hz. APP are natural noises in the atmosphere, originating from very diverse sources. Their intensity and frequency range are very changeable.

One of the main sources of APP in the atmosphere is the chaotic turbulent noise of airflows (Gossard and Hooke 1975; Lumley and Panofsky 1964). Thus all kinds of windy weather are accompanied by APP. Turbulent APP include infrasonic, sonic and even ultrasonic components (Lumley and Panofsky 1964), of which APP of very low frequencies, below 1 Hz, make the major contribution. The total amplitude of turbulent APP depends on the power of the atmospheric disturbance and can reach hundreds of pascals in rough weather.

In addition to the turbulent APP, there exist, localised within the disturbed areas of the atmosphere, some types of wave disturbances that can transfer oscillations of air pressure a long way from their source (Bull et al. 1988; Gossard and Hooke 1975). Of these two main types make a major contribution to APP in the calm domains of the atmosphere: infrasounds and internal gravity waves.

The atmospheric causes of infrasonic waves are wind-induced turbulence and convective processes. Their amplitude can reach tens of pascals. Apart from weather phenomena, infrasonic waves can be generated by sea waves, earthquakes and solar eclipses. The damping decrement of atmospheric infrasounds decreases as their frequency diminishes, thus they can often be found many thousands of kilometres away from their origin. Some atmospheric infrasonic waves can reach the middle latitudes from the polar light zones and are correlated with solar flares and magnetic storms (Bull et al. 1988).

The internal gravity waves in the atmosphere have a slight similarity to gravity waves on the surface of a liquid. They are primarily caused by shear flows and convection (Romanova and Yakushkin 1995). Gravity waves become many times stronger before sudden weather changes (Xie Jin-lai et al. 1988). The oscillation periods of gravity waves, observed near the surface of the earth, range from minutes to hours. The amplitude of internal gravity waves can reach hundreds of pascals and shows a positive correlation with precipitation.

There are good reasons to suppose that APP can influence living organisms. On the one hand, in the upper part of its frequency range, f~1 Hz, this factor is close to that of ordinary technical infrasounds. Typically, technical devices produce infrasounds with frequencies higher than 1 Hz. It has been shown in a number of studies that infrasounds in the frequency range 1–20 Hz can have negative effects on man, e.g. annoyance, fatigue, fear, depression, internal pains (Broner 1978; Bull et al. 1988; Gavreau 1968). Mental work capacity was shown to decrease on exposure to infrasound. The sensitivity threshold of human beings to infrasound is, according to various authors, 80–90 dB (0.2–0.6 Pa). Obviously, the alternating pressure level of natural APP frequently exceeds these values.

On the other hand, APP of much lower frequencies (f<<0.1 Hz) with amplitudes of tens or hundreds pascals are similar to very fast variations in barometric pressure with a rate considerably exceeding the critical value of 2–4 hPa in 3 h. For example, a typical internal gravity wave with an amplitude of 40 Pa and an oscillation period of 20 min provides a dp/dt rate of up to 12.6 Pa/min. Thus one can also expect APP of extremely low frequencies to have biological effects. Nevertheless, their contribution to human meteororeactions is still unexplored.

As already mentioned, some elements of natural infrasonic waves have a relationship with solar flares. Turbulent APP and gravity waves are also sensitive to solar activity because weather-forming processes in the atmosphere are influenced by solar flares and solar wind, especially at high latitudes (Pudovkin and Raspopov 1993). Consequently, low-frequency atmospheric noise, if it were biologically active, could be one of the factors transmitting the influence of solar activity to the biosphere (Vladimirsky 1982). Confirmation of this hypothesis would stimulate the exploration of the so far poorly understood links between the cosmos and the biosphere.

Only a few communications have been published on the biological effects of APP. Human reactions to weather changes and "micropulsations" of atmospheric pressure were reported by Mezernitsky (1934). He believed that the disadaptation induced by such micropulsations in sick people was frequency dependent and was associated with disorders in the dynamics of nervous processes.

Natural APP can probably influence some kinds of human behaviour. A correlation between strong natural infrasonic waves and automobile accidents, as well as absenteeism among schoolchildren in the Chicago area, has been reported (Green and Dunn 1968). The well-known characteristic of heightened anxiety levels in people with nervous or mental disorders at considerably increased wind speeds is likely to be a result of the influence of natural APP created by wind-induced turbulence. As "weather sensitivity" symptoms even occur in people staying indoors, the causal factor must be a physical agent reaching into enclosed spaces. APP can penetrate buildings and therefore could be responsible for weather sensitivity in humans (Richner and Graber 1978).

This research was undertaken to answer the following questions: can natural APP cause noticeable physiological responses in human beings and, if so, in what manner do such effects depend on the physical characteristics of APP? For that purpose, a group of healthy volunteers were exposed to specially generated **atmospheric pressure oscillations (APO)**, modelling natural APP. The frequency range and amplitudes of the APO applied were typical for the passage of a weather front (indoor observations of natural APP in Kiev during 1990–1991 were used for comparison).

Higher nervous activity was chosen as an indicator of the physiological response to APO exposure, taking into account its susceptibility to environmental changes (Persinger 1987; Suchkina 1985; Troshin and Suchkina 1986). Changes in attention and short-term memory functions as well as changes in mental processing dynamics were examined. In addition, some basic physiological parameters associated with central mechanisms of the maintenance of mental activity were measured.

Methods

Experimental design

The objective of the experiments was to detect and measure changes in the indices of mental and behavioural activity of the subjects when exposed to specially generated APO modelling natural APP. The experiments were carried out in an ordinary working room, not in a pressure chamber, because the APO applied were very small, compared with atmospheric pressure. APO were created by means help of a specially designed generator.

Each experiment was executed in accordance with the same fixed scheme (Fig. 1). At the beginning, the initial values of the psycho-physiological characteristics of the experimental subjects were tested. Then APO were switched on and, 15 min later, the battery of tests was repeated under influence of the APO. The 15-min gap between the first testing and the re-testing was chosen to "accumulate" the influence of APO in order to make any changes in the subject more detectable. Each experiment lasted for 50–55 min. The subjects participated in the experiments once a day. Each subject participated at the same time every day in order to neutralise the influence of any 24-h rhythm. In control trials, APO were absent, but the subjects did not know whether APO had been applied to them or not. The experiments with different types of APO and control trials were performed in a randomised order.

The following kinds of APO were applied in the experiments:

1. Periodic APO, close to sinusoid, with oscillation periods of 15, 30, 45, 90 s and amplitudes of 50 Pa, and also periodic APO with a period of 6 s and an amplitude of 30 Pa
2. A quasi-chaotic signal modelling natural APP, synthesised by adding several sine waves, with oscillation periods from 10 to 150 s and a total amplitude of 50 Pa

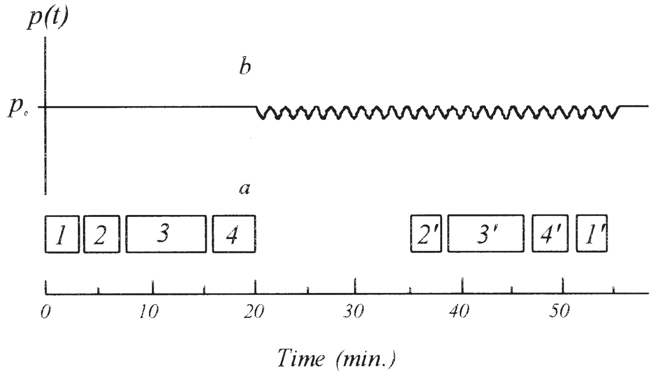


Fig. 1 Time schedule of tests (**a**) and APO influence (**b**) in the "active" experiment: *1* and *1'* heart rate and breath-holding measurements; *2* and *2'* short-term memory testing; *3* and *3'* "proof-reading" test; *4* and *4'* "red-black table" test. $p(t)$ Periodic APO created by the generator (the 90-s oscillation period is chosen as an example); p_0 atmospheric pressure

Each subject participated three times in the experiments, with each kind of APO, and in at least three control trials. The overall number of the experiments exceeded 250.

Subjects

The group of the experimental subjects consisted of 12 healthy volunteers, 35–50 years of age, 5 male and 7 female. All of them were informed about the character of the experiments. Most of the subjects claimed they did not react to ordinary weather changes. All participants were members of scientific staff from the Institute of Physics of the National Academy of Sciences of Ukraine. They had normal sight and had experience of operating an IBM-type personal computer used for psycho-physiological testing. During the days before the beginning of the experiments, the subjects received training in order to become accustomed to the tests. They were asked to achieve the highest results in terms of the rate and accuracy of task performance during the experiment, but the experimental situation was not stressful.

Psychological tests

The widely known "proof-reading" method was used for testing the attention of the subjects. It was implemented as a computer-administered test. The subject performed a proof-reading test for 6 min after a short practice of 1.5 min. For each minute, the computer calculated the current value of the proportion of mistakes made by the subject. The index of inattention was computed as the average proportion of mistakes. The standard deviation of the proportions of mistakes over consecutive minutes served as an index of attention instability. Additionally, the computer routine calculated the performance rate as the average speed of scanning the table used in the test.

The quality of short-term memory was assessed by a classical method of recognition of memorised objects (Woodworth 1938), also using a personal computer. After 1 min of memorising given symbols, the ability of the subject to recognise them among others was tested for 1 min. The proportion of mistakes served as an index of the inaccuracy of recall.

A modification of Schulte's method, known as a "red-black table" (Leontyev and Gippenreiter 1972), was applied in order to test mental processing flexibility. The experimental material consisted of a large set of cards containing a table of 49 (7×7) squares with randomly distributed "number-letter" pairs, e.g. **1-h**, **23-e**. Of these, 25 pairs with numbers from 1 to 25 were red, the others with numbers from 1 to 24 were black. All the cards were different to avoid memorising. Having received two cards, the subject had to perform the three following tasks:

1. Write down the letters of one colour from the first card in increasing order of the associated numbers during the first minute.
2. Write down the letters of the other colour from the same card in decreasing order of the associated numbers during the next minute.
3. Write down the letters of one colour in increasing order of the associated numbers, alternating them with the letters of the other colour in decreasing order of the associated numbers from the second card for the next 2 min.

The index of mental processing flexibility was determined by the number of letters written out correctly from the second card (task 3) divided by the total number of letters written out correctly from the first card (tasks 1 and 2).

Physiological and meteorological variables

Changes in the functioning of the cardio-respiratory system in the subjects exposed to APO were also important, recognising the sensitivity of that system to fluctuations in meteorological parameters (Baevsky et al. 1997; Choisnel et al. 1987; Kolosova and Mindlina 1987; Strestik and Sitar 1996; Temnikova 1977) and its participation in the maintenance of mental activity (Baevsky 1979; Fonsova et al. 1990). Therefore heart rate was measured in the experiments as an elementary index of cardiac activity, and the functioning of the respiratory system was assessed by measuring voluntary breath-holding duration after a short exhalation. In addition to these basic observations, at the beginning of each experiment the subjects estimated their own physical and mental condition. Subjective sensations of participants during the experiments were also noted.

Local meteorological parameters displayed by the meteorological station at Kiev were recorded. The experiments were conducted when natural barometric pressure did not change by more than 1 hPa per hour and the total amplitude of natural APP within the laboratory was not higher than 5 Pa.

Data processing and statistical methods

As described in the experimental design, the subjects were tested twice, before and after switching on the APO. In each experiment, relative changes in the studied indices were calculated using the formula

$$\partial D = \frac{D_2 - D_1}{D_1} \cdot 100\%, \qquad (1)$$

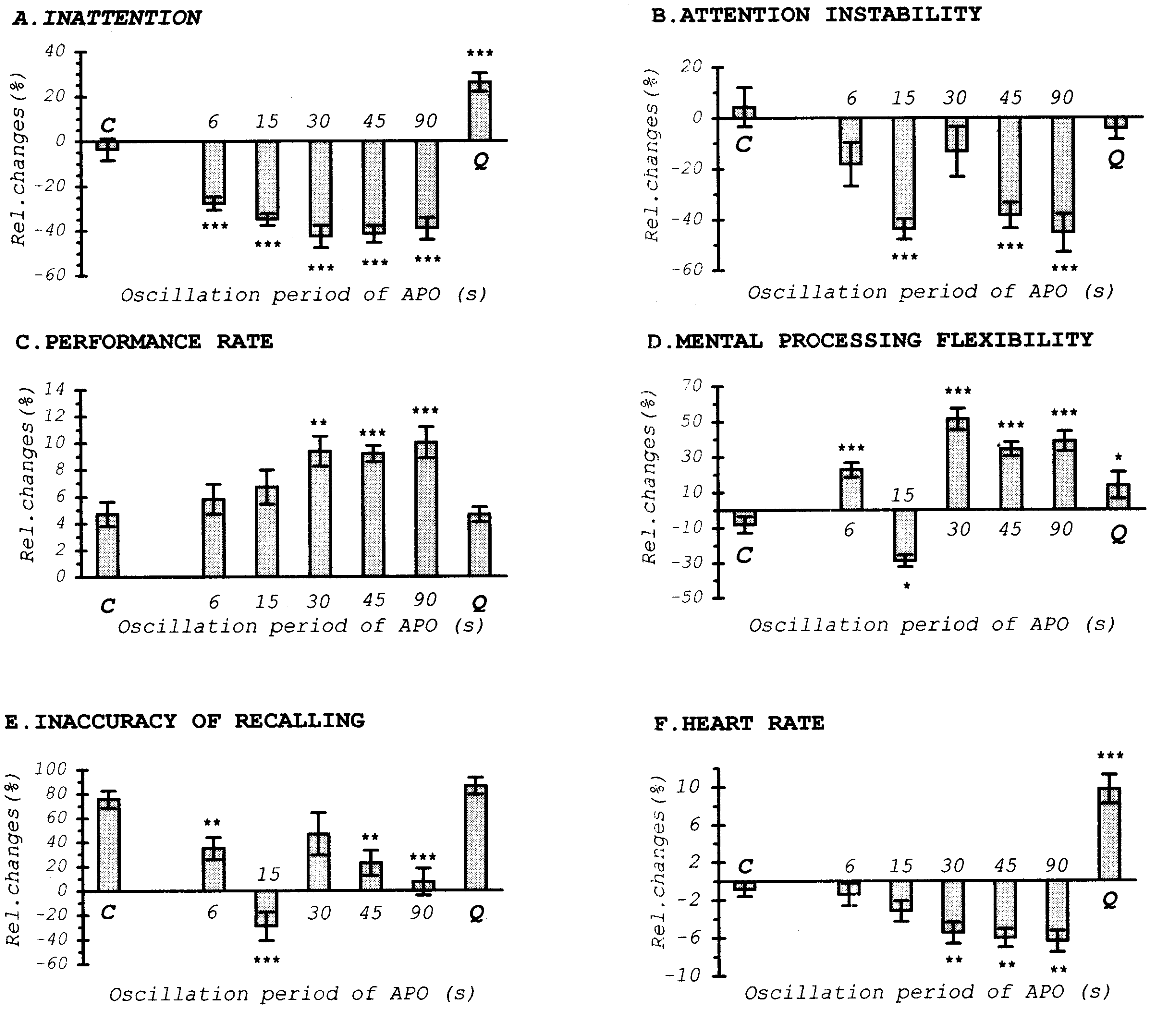
where D_1 and D_2 are measurements obtained at the first and the second testing.

Relative changes in each index for different kinds of experiments were considered as separate sets. Application of Kolmogorov-Smirnov and Lilliefors criteria showed that, within those sets, individual empirical data did not deviate significantly from the normal distribution. Relative changes in each index for a given type of experiment were averaged over the group of subjects and standard error values were calculated. Statistical significance of the difference between the group averages obtained under each kind of APO influence and in the control trials was determined using Student's *t*-test for independent samples.

APO generation and measurement

The generator of APO consisted of a ventilation unit connected to the working room by means of an air guide containing a shutter. Air pressure in the room oscillated due to periodic movements of the shutter, which was controlled by computer commands with the help of a stepping electric motor. Such a technical solution is more convenient than a cylinder and plunger system, commonly used for infrasound generation, as it provides pressure oscillations of very low frequencies in an ordinary unpressurised room.

All parameters of the acoustic signal applied, such as amplitude, frequency, coherence, signal form and the time schedule,



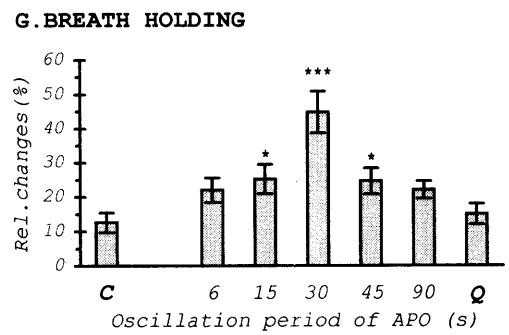


Fig. 2 Relative changes in psychological and physiological indices under various kinds of APO and in control. (***C*** Control experiments; ***Q*** quasi-chaotic APO. Values: group average ±SE. Significance of difference vs control: * $P<0.05$, ** $P<0.01$, *** $P<0.001$)

were controlled by a computer routine and checked by the APO measurer. Variable pressure levels up to 70 Pa in the frequency range 0.001–0.2 Hz were reproducible by the APO generator. Thus the corresponding oscillation periods of APO could vary from 5 to 1000 s. Air pressure oscillations were identical all over the room, so the experiments with the subjects could be carried out under ordinary working conditions. The experimental equipment could switch APO on and off without any noticeable changes in the environment.

The characteristics of acoustic signals created by the generator (APO) and those of natural atmospheric noise (APP) were measured with the help of a highly sensitive membrane transducer, which was specially designed at the Institute of Physics. The measurement system also included a signal amplifier and a plotter. APO and APP could be measured in a frequency range 0–20 Hz. The sensitivity threshold was about 0.2 Pa.

Results

Relative changes in psycho-physiological indices, observed under various kinds of applied APO (experimental trials) and in the absence of APO (control trials), are presented in Fig. 2A–G. All the findings have been averaged over the group of subjects. As each subject participated in a given type of experiment three times, each column in Fig. 2 represents an average of 36 measurements.

Control trials

In the control trials, most individual characteristics did not change significantly during the experiment (column

C in each graph in Fig. 2). In the individual findings, the difference between the first and the second testing varied not only in value but in sign too. This could be the result of a difference in the initial functional state of the subjects and in their response to mental load. However, the majority of the indices averaged over the group showed a tendency to changes of one sign. In particular, short-term memory considerably worsened in the re-testing (Fig. 2E). Some participants noted that their memory was not so clear in the re-testing as it was at the first testing, although their attention level remained high. A positive tendency was more pronounced for performance rate and breath-holding duration. This was probably a result of training during the first testing.

The signs of changes in psycho-physiological indices in the control trials depended to some extent on their initial values. A positive tendency prevailed in the subjects with a lower than average initial level of mental activity.

Experimental trials

In the experimental trials, the difference in indices between the first testing and the re-testing was considerably greater than that in the control trials (Fig. 2). As a whole, all the kinds of APO applied showed some stimulating influence on task performance. However the character of the subjects' responses to periodic APO and to a quasi-chaotic signal (column **Q** in each graph) appeared to be different.

Periodic APO positively influenced the indices of mental activity in many cases. Improvement in attention function was the most unequivocal result (P<0.001) of the exposure to all kinds of periodic APO (Fig. 2A). The most pronounced effects by comparison with the control trials took place when APO with oscillation periods of 30, 45 or 90 s were applied. Significant improvements in nearly all measured parameters of mental activity observed in those cases were accompanied, as a rule, by a slowdown in heart rate (Fig. 2F) and an increase in breath-holding duration (Fig. 2G). It was noticeable that the positive effects of periodic APO were definitely stronger in the subjects with a lower initial level of mental activity.

Periodic APO (30 s) exerted the strongest positive influence on mental processing flexibility (Fig. 2D). A statistically significant effect was noted, independent of the initial level of mental activity in the subjects. At the same time, short-term memory (Fig. 2E) and attention stability (Fig. 2B) improved under that level of APO, as compared with control trials, only in those individuals who had a lower initial level of mental activity. Periodic APO (30 s) could cause excessive stimulation in subjects with higher than average initial mental activity. If so, this could impede retention of information in short-term memory.

Positive but less pronounced effects on mental efficiency were found in the experiments with periodic APO (6 s). A weaker response might be characteristic of that level of influence but it should be remembered that the amplitude of APO (6 s) was lower than in other cases.

The feature of periodic APO (15 s) was that they significantly improved only some of the indices; others either worsened or did not change. In particular, a significant improvement in attention and short-term memory functions was accompanied by a decrease in mental processing flexibility. It is probable, that 15-s periodic APO benefit repetitive operating activities by promoting a steady stereotypical behaviour and facilitating information retention in short-term memory.

Contrary to periodic APO, quasi-chaotic APO, modelling stochastic APP in the natural atmosphere, had a negative influence on a number of psycho-physiological characteristics of the subjects. A statistically significant deterioration in attention (Fig. 2A) was accompanied by a rise in heart rate (Fig. 2F). Other measured parameters did not significantly change in comparison with control trials differing considerably in individual subjects both in value and sign. Significant positive changes were observed only for mental processing flexibility (Fig. 2D). Quasi-chaotic APO may have some stimulating (positive), though disorganising (negative), effects on a purposeful mental activity when prolonged, steady concentration is essential.

It should be noted that cases of worsening physical or mental condition in the experimental subjects, or in the research personnel, in a course of experimental trials were not observed. Neither were there any negative aftereffects associated with exposure to APO. In most cases the subjects did not experience any unpleasant sensations, except for the experiments with quasi-chaotic APO when some participants claimed that "something prevented them from performing the task better". Experimental observations of changes in heart rate, blood pressure and body core temperature induced in human beings by exposure to APO will be published separately (preliminary results were reported in Delyukov et al. 1996).

Discussion

APO used in these experiments were very weak, compared with the absolute value of atmospheric pressure. Comparable changes in air pressure can be easily obtained by puffing or with the help of a small ventilator. Nevertheless, psycho-physiological characteristics significantly changed in the subjects as a result of a short exposure of 15–30 min to APO. Heart rate has demonstrated a much faster response (Delyukov et al. 1996). Physiological effects caused by APO could be reliably detected despite the relatively small number of subjects participating in the study. Gender differences in the response to APO were not found, probably because of the large variance in the individual indices and the small group size.

It is widely known that infrasound influences mental activity negatively. By analogy to infrasound, the negative effects of APO on task performance could be expected. Surprisingly, periodic APO with frequencies between 1/30 and 1/90 Hz definitely improved mental efficiency. One can conclude that APO find some useful resonance in man in that frequency band. If so, the detrimental effects of stochastic APO on attention are not very surprising. Interestingly, the frequencies at which APO effects were observed coincided with the very low frequency range of heart rate variability (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996) and also the range of super-slow electrical activity of the brain that is believed to accompany the formation of functional states (Alajalova 1979). The effects of APO and APP on heart rate variability are currently under investigation.

The total amplitude of natural APP in the middle latitudes periodically exceeds the amplitudes of APO used in the experiments in this study. Consequently, natural APP also have the potential to affect human beings, thus contributing to meteororeactions in man, particularly if one takes into account their prolonged action. Being associated with weather-forming processes, solar flares and magnetic storms, they can indeed link living organisms with various natural and cosmic phenomena, as was presupposed by Vladimirsky (1982).

The biological effects of APP occurring in nature are not fully understood. It may be assumed that, as far as APP are expected to have a stimulating effect, there must exist an optimal range of the intensity of APP in the environment promoting normal activity in human beings. If so, the lack of APP in the environment might result in passiveness and lower work capacity. On the contrary, excessive, especially stochastic, APP can potentially impair the accuracy of task performance. More pronounced effects of APP, both positive and negative, can be expected in people suffering from mental or physical health problems. Studies of the effects of APP should improve our understanding of the nature of meteorosensitivity.

In addition, the intensity and the frequency range of natural APP are very changeable, and humans have no conscious perception of APP. These two characteristics, in combination with the effects of APP on alertness and memory, make APP a potentially hazardous factor, which might influence environmental safety, e.g. in traffic or at the workplace. This is yet further justification for the task of assessing the environmental role of APP.

Acknowledgements This work was supported by the State Committee on Science and Technology of Ukraine. The authors gratefully thank Gertruda V. Klimusheva and Oleg G. Sarbey for their support of this research at the Institute of Physics of the National Academy of Sciences of Ukraine. Computer analysis of the psycho-physiological tests by Il'ya A. Obukhov and technical contributions from Vitaly M. Bondar are also appreciated.

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