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AN INVESTIGATION OF THE EFFECTS OF NEGATIVE AIR IONS ON RESPONSES TO SUBMAXIMAL EXERCISE AT DIFFERENT TIMES OF DAY

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The influence of negative air ions on rectal temperature (T_r), heart rate (HR), oxygen uptake ($\dot{V}O_2$) and ventilation ($\dot{V}E$) was examined in male subjects ($n=8$) at rest and during two successive exercise bouts of 90 W and 180 W, each for 20 min on a cycle ergometer. Exposures at 4 different times of day (01:30, 10:00, 14:00 and 18:00 h) were presented to subjects under experimental and control conditions using a cross-over design. Results indicated that negative air ions significantly reduced resting values of all physiological variables (p between 0.05 and 0.01): these effects tended to disappear under exercise conditions, except for T_r. There was no significant effect of air ions on state anxiety pre- or post-exercise or on the perception of effort ($p>0.05$). The significant circadian rhythm in T_r was reduced in amplitude by air ionisation although it retained its normal phase. Results confirm that negative air ions are biologically active and that they do affect the body's circadian rhythmicity.

Air ions may be produced in nature by events such as shearing of water droplets in a waterfall, rapid flow of great volumes of air over a land mass, by solar and cosmic radiation, as well as a variety of radioactive sources. The ions are produced by forces resulting from displacement of an electron from a molecule of one of the common atmospheric gases. The molecule is left with a positive charge whilst the displaced electron is normally captured by another molecule to which it imparts a negative charge.

Air ions are generally recognised as biologically active. Negative air ions are thought to promote beneficial mood states whilst positive air ions have been shown to cause characteristic complaints from subjects (HAWKINS and BARKER, 1978). Accordingly, negative air ion generators are commercially available for office and

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domestic environments to enhance mood and performance. Indeed, HAWKINS and BARKER (1978) provided evidence that negative air ions produced positive effects on psychomotor and mental functions.

Favourable effects may extend to conditions of physical exercise as SOVIJARVI et al. (1979) showed that perceived exertion during an incremental exercise test was lowered by an excess of negative air ions compared to a condition of excess positive ions. This was supported by the work of INBAR et al. (1982) who reported that the elevation in heart rate and core temperature during exercise was less pronounced on exposure to negative air ions compared with neutral air.

The mechanisms through which the effects of air ions are mediated may include brain levels of serotonin (KRUEGER, 1973), body temperature (STRYDOM et al., 1976) and oxidative metabolism (KRUEGER and SMITH, 1960). All of these functions vary with the 24 h solar day and so exposure to air ions may disturb normal circadian rhythms. HAWKINS and BARKER (1978) reported that subjects exposed to negative air ions demonstrated a flattening of the normal curve in performance (mirror tracking, reaction time and pursuit rotor): in contrast, performance on exposure to positive air ions showed an exaggerated decline in the evening compared to a control condition.

The purposes of the present study were therefore twofold:

i) to examine the effects of negative air ions on physiological and subjective response to submaximal exercise; and
ii) establish any influence of time of day on such effects.

METHODS

Subjects. Eight males, aged 19–25 years, participated in the experiment after giving written informed consent. All were relatively experienced in physical training and none had any respiratory ailments at the time of the experiment.

Experimental design. Subjects were exposed to negative air ions in an enclosed exercise laboratory: a neutral air environment was used for control purposes. The exposures were presented to subjects at four different times of day—01 : 30, 10 : 00, 14 : 00, and 18 : 00 h. The order of experimental conditions was balanced, four subjects completing the ionized condition first to avoid an order effect. For each subject, a minimum of 2 weeks separated the trials to avoid residual effects of ionization when the experimental condition was completed first: otherwise a minimum of 1 week separated the conditions. Tests at the different times of day were presented on separate days in random order.

Measurements were made at rest pre-exercise of rectal temperature, heart rate, oxygen consumption ($\dot{V}O_2$) and minute ventilation ($\dot{V}E$). These measurements were repeated during a 40-min submaximal exercise bout during which perceived exertion was also rated.

Procedure. Four air ionizers (Sidha Mountain Breeze, Skelmersdale) were

Table 1. Resting physiological measures at 4 different times of day in neutral conditions and on exposure to negative air ions.

Variable		Time of day (h)			
		01:30	10:00	14:00	18:00
Rectal temperature (°C)	Control	36.85±0.17	37.09±0.32	37.23±0.27	37.35±0.26
	Ionized	36.75±0.19	36.93±0.15	37.00±0.20	37.04±0.22
Heart rate ($\text{beats} \cdot \text{min}^{-1}$)	Control	62±8	66±8	67±6	63±7
	Ionized	57±8	62±7	62±8	61±6
$\dot{V}O_2$ ($\text{ml} \cdot \text{min}^{-1}$)	Control	214±93	265±60	293±87	260±79
	Ionized	228±69	219±108	246±90	260±78
$\dot{V}E$ ($l \cdot \text{min}^{-1}$)	Control	9.49±3.60	12.91±4.09	12.93±5.67	11.74±2.57
	Ionized	9.42±3.01	10.89±4.53	11.40±4.53	11.11±6.22

Mean (±SD) values for 8 subjects are given.

used to negatively ionise the environment. These were placed at head height and within 1 m of the subject seated on a cycle ergometer. Subjects were grounded via the earth electrode on an ECG (Sanei, Tokyo) to ensure biological delivery of the experimental ions. An attempt was made to make the experimental procedure blind for subjects by covering plug sockets and the fluorescent lights from the ionisers. The output of each ioniser was checked in the manufacturers' laboratory and found to produce 172,000 ions/cm^3 at a distance of 1 m.

In the experimental condition, the air ionizers were switched on 30 min prior to the scheduled arrival of the subject. A 30-min period was then allowed for habituation to the laboratory environment. Before this period commenced, the subject was connected to the ECG using three chest leads. The subject then had a period of about 15 min sitting on a cycle ergometer (clad in shoes, socks, shorts and 't' shirt): during this time measurements were made of state anxiety according to SPIELBERGER et al. (1970). Measurements were made of psychomotor and cognitive tasks, the results of which are not reported here. Resting heart rate was then measured over a 30-s sample and core temperature recorded using a rectal probe (Lights Laboratories, Brighton). Resting $\dot{V}O_2$ was then measured over a 5 min period using the Douglas bag method of collecting expired air. Gases were analysed using infrared and paramagnetic methods (P. K. Morgan, Chatham) and a dry gas meter (U.G.I., London) for minute ventilation ($\dot{V}E$).

On completion of the resting measurements, the subject removed his shirt and commenced pedalling on the cycle ergometer (Monark) at 60 $\text{rev} \cdot \text{min}^{-1}$ and a power output of 90 W. During 20 min exercise at this load the subject was again presented with the psychomotor and cognitive tasks, not reported here. The $\dot{V}O_2$ was calculated from a 1-min sample of expired air collected during the 10th min of exercise. Measurements were made of rectal temperature and heart rate, during the 20th min of exercise. Perceived exertion was rated using BORG's (1970) scale. After a 2-min rest, the exercise intensity was raised to 180 W and the procedures repeated, except that the cognitive task was omitted. State anxiety was again recorded post-exercise.

During the 6-week period of experimentation, the mean temperature in the laboratory was 18°C. The relative humidity varied between 45–63% but was balanced between the conditions.

Statistical analysis. The data were treated with a three-way ANOVA using the Genstat statistical software package. The model incorporated a term for subjects, experimental treatments and time of day, and included an interaction term. Delta values (exercise minus rest) for the physiological measures were analysed with the same ANOVA model.

The time of day effect was further examined using cosinor analyses to check for circadian rhythmicity (NELSON et al., 1979). This analysis took into consideration the unequal time intervals between observations. A *t*-test was used to test for effects of the air ionization on the amplitude of circadian rhythms found to be statistically significant. For all statistical tests a p value of 0.05 was set for significance.

RESULTS

Sitting at rest in the ionized environment brought a significant reduction in core temperature. Values averaged over the four times of day decreased from 37.1°C in normal conditions to 36.9°C ($F=5.7$; $p<0.05$). A significant reduction was also noted in heart rate from 65 to 60 beats·min^{-1} ($F=14.1$; $p<0.01$). A similar trend was evident in $\dot{V}O_2$, mean values being 258 ml·min^{-1} in the neutral environment and 238 ml·min^{-1} in the ionized condition ($F=6.2$; $p<0.05$). Corresponding values for $\dot{V}E$ were 11.77 and 10.70 l·min^{-1}, this difference being significant ($F=4.4$; $p<0.05$).

The submaximal exercise bouts caused rectal temperature to increase on average (over the four times of day) by 0.15°C at 90 W and 0.45°C at 180 W. The difference in rectal temperature between the ionized and neutral environments were still evident at both 90 W ($F=8.5$; $p<0,05$) and 180 W ($F=9.4$; $p<0.01$) work rates. No difference between conditions was noted in the rise in rectal temperature during exercise.

No significant differences between conditions were found when the absolute and delta (exercise minus rest) values of heart rate, were formally examined. The overall mean heart rates (±SD) in response to exercise at 90 W and 180 W respectively did not differ between the neutral and the ionized conditions. The average values, calculated after combining the four observations at the different times of day for each subject, are given in Table 2. Similarly, there was no significant effect of air ions demonstrated in the responses of $\dot{V}O_2$ and $\dot{V}E$ to exercise at 90 or 180 W. When delta values were analysed, a significantly greater rise was noted in $\dot{V}O_2$ ($F=9.0$; $p<0.05$) at 90 W and in $\dot{V}E$ at both 90 W ($F=9.0$;

Table 2. Mean values (±SD) for responses to submaximal exercise at two intensities under neutral and negative air ion conditions.

		Control	Ionized
Heart rate (beats·min^{-1})	90 W	105±8	152±15
	180 W	152±15	152±15
$\dot{V}O_2$ (ml·min^{-1})	90 W	1,001±260	1,143±170
	180 W	2,453±341	2,520±202
$\dot{V}E$ (l·min^{-1})	90 W	33.6±7.1	36.6±5.4
	180 W	67.8±14.6	68.5±10.1

Values for the four different times of day were averaged for each subject and each of the two conditions.

$p<0.05$) and 180 W ($F=8.4$; $p<0.05$) in the experimental compared with the neutral environment.

Variability between subjects was found for rectal temperature at 90 and 180 W when both measured and delta values were analysed (p values beween 0.05 and 0.001). Heart rate at rest and during both exercise bouts also varied between subjects ($p<0.001$). Significant inter-subject variability was also found for $\dot{V}O_2$ at rest ($F=8.7$; $p<0.001$) and 180 W ($F=2.7$; $p<0.05$) and for $\dot{V}E$ at rest ($F=11.4$; $p<0.001$) and 180 W ($F=9.6$; $p<0.001$). None of the interaction terms for any of the variables measured produced a significant result.

The effect of time of day was extracted as a separate factor in the ANOVA model. The mean heart rates were 57, 62, 62, and 61 beats·min^{-1} for the ionized condition compared to 62, 66, 67, and 64 beats·min^{-1} for the neutral environment at 01:30, 10:00, 14:00, and 18:00 h, respectively. Although these figures suggest circadian variation, the time of day effect was non-significant according to ANOVA. According to ANOVA, significant time of day effects were noted in rectal temperature at rest ($F=8.2$; $p<0.001$), and during exercise at 90 W ($F=5.2$; $p<0.01$) and 180 W ($F=5.6$; $p<0.01$). The rise in rectal temperature during exercise did not vary with time of day. A significant time of day effect was noted also in $\dot{V}O_2$ ($F=3.6$; $p<0.05$) and in $\dot{V}E$ ($F=4.9$; $p<0.05$). These effects were not demonstrated in the responses to exercise, either for absolute (exercise) or delta (exercise minus rest) values (Table 3).

Those variables demonstrating an influence of the time of day were further examined to establish whether a cosine function fitted the data. A significant rhythm was evident in rectal temperature at rest (Table 1), the acrophase (or timing of the highest point in the curve) occurring at 16:18 h in the control condition and 15:38 h in the ionized exposure. The amplitude of the rhythm was reduced from 0.27 to 0.15°C by air ion exposure ($p<0.05$). The acrophase was calculated to occur at 15:41 and 15:29 h for exercise at 90 W and at 180 W, similar values being found for control and experimental conditions. The mean reduction in amplitude due to air ionization was 0.07 and 0.06°C at 90 and 180 W, although

Table 3. Mean (±SD) in responses to exercise at 90 W and 180 W at four different times of day ($n=8$).

	Time of day (h:min)			
	01:30	10:00	14:00	18:00
Rectal temperature (°C)				
90 W Experimental	36.84±0.17	37.01±0.17	36.98±0.28	37.05±0.24
Control	36.95±0.20	37.17±0.39	37.19±0.31	37.30±0.18
180 W Experimental	37.16±0.21	37.30±0.23	37.33±0.28	37.35±0.24
Control	37.24±0.24	37.50±0.37	37.46±0.28	37.61±0.19
Heart rate (beats·min^{-1})				
90 W Experimental	102±9	102±9	105±13	106±11
Control	101±10	109±11	108±13	103±7
180 W Experimental	151±16	151±16	152±13	155±16
Control	148±16	157±15	156±16	151±15
Perceived exertion				
90 W Experimental	10.5±1.7	10.4±1.5	10.1±0.8	10.5±1.2
Control	10.5±1.3	11.8±2.1	11.2±2.8	10.3±2.1
180 W Experimental	14.8±1.8	14.5±1.8	14.5±1.2	14.6±1.4
Control	14.9±2.0	15.6±2.1	15.1±2.5	14.8±2.1
$\dot{V}O_2$ (ml·min^{-1})				
90 W Experimental	1,119±169	1,112±241	1,286±118	1,112±159
Control	922±205	1,088±235	1,056±378	1,000±124
180 W Experimental	2,518±236	2,499±312	2,499±147	2,569±326
Control	2,336±309	2,561±245	2,680±469	2,357±400
$\dot{V}E$ (l·min^{-1})				
90 W Experimental	35.65±5.36	36.11±7.05	40.96±6.40	35.54±2.63
Control	30.98±6.12	36.86±7.57	33.91±9.12	34.36±5.56
180 W Experimental	67.00±9.85	70.21±7.83	67.58±8.72	69.91±14.75
Control	64.01±15.88	70.40±12.30	76.24±14.42	64.96±15.76

these changes were non-significant.

The $\dot{V}O_2$ at rest showed a significant rhythm only in the neutral environment. The acrophase was calculated to occur at 13:30 h ($p<0.05$).

The rating of perceived exertion differed between subjects at both 90 W ($F=9.6; p<0.001$) and 180 W ($F=34.4; p<0.001$). No influence of air ions was found in this variable at either work rate. Neither was there a significant effect of time of day on the perception of effort and the interaction term was non-significant.

DISCUSSION

The present observations confirmed that negative air ions produce biological effects since significant reductions were found in rectal temperature, heart rate, and metabolic rate at rest on exposure to negative air ionization. It has been shown *in vitro* that large doses of negative air ions promote efficiency of aerobic metabolic processes (KRUEGER and SMITH, 1960; KRUEGER and REED, 1976). This could partly account for the decreases noted here at rest in $\dot{V}O_2$ and $\dot{V}E$ and consequently in heart rate. Additionally, INBAR et al. (1982) have suggested that coupling of electron transport and ATP synthesis is more efficient under the influence of small negative air ions, causing less liberation of heat energy. However, the changes in $\dot{V}O_2$ due to air ionization in the present study were comparatively greater than those in body temperature. Assuming a Q_{10} of 2.0, a decrease of about 0.5°C in core temperature would be needed to match the $20\,ml \cdot min^{-1}$ mean fall in $\dot{V}O_2$, compared to the 0.2°C decrease actually observed. Thus, factors other than thermal mechanisms may operate to exert an influence of air ions on tissue metabolism.

Thermoregulatory and hormonal mechanisms would also affect the heart rate as does the anxiety state. OLIVEREAU (1975) concluded that alterations in blood levels of serotonin induced by air ions cause changes in endocrine and CNS functions which in turn alter basic physiological processes. A reduction in the amount of serotonin in the mid-brain was linked with the tranquillising action of both negative air ions and reserpine, a drug used to treat hypertension. However, no relation was evident in the present study between heart rate and anxiety, since the latter did not vary with air ionization either at rest or post-exercise.

The effects of air ions on metabolism and heart rate tended to disappear under exercise conditions. This was complemented by the failure of the experimental treatment to affect the perception of effort. These observations are opposite to those of SOVIJARVI et al. (1979) who noted a tendency towards lower heart rates and ratings of exertion on exposure to negative air ions than when exposed to positive air ions, a comparison that would nurture a significant result. In the present study, the perception of effort tended to be rated lower in the experimental condition but only at 180 W and the effect did not reach significance (see Table 3). The possibility that individual sensitivity swamped the effects of air ions on the responses to exercise was not supported by the statistical analysis as none of the interactions was significant. Individual variability in responsiveness to air ions was shown by CHARRY (1984) using reaction time as a criterion.

The effect of negative air ions on rectal temperature evident at rest persisted under both submaximal exercise intensities. The difference of 0.2°C was small and of little practical significance for light levels of exercise. However, the effect could have important implications for conditions when thermoregulatory requirements place limits on exercise performance. This would apply at higher intensities and longer durations of exercise than in the present investigation. It would also be relevant when heavy physical work has to be sustained in hot environments.

Characteristics of the circadian rhythm observed in rectal temperature correspond with observations in the literature (REILLY and BROOKS, 1982; REILLY, 1990). The consistency of the exercise-induced rise in rectal temperature with time of day is in agreement with previous observations (REILLY and BROOKS, 1986). The flattening of the curve in body temperature caused by exposure to negative air ions supported the hypothesis of HAWKINS and BARKER (1978) whose views were based on performance rhythms. It is well known that performance in many psychomotor tasks follows the normal circadian curve in body temperature (REILLY, 1987). To what extent the effects of air ions on the body temperature rhythms and on performance rhythms noted by HAWKINS and BARKER (1978) are due to common mechanisms cannot be established from present data. The effect may be mediated by brain serotonin levels which are known to be affected by air ion doses and are implicated also in the central neural control of circadian rhythms (YATES and HERBERT, 1976).

The present observations confirm that negative air ions are biologically active but their effects are diminished when physiological responses to exercise are considered. The effect on rectal temperature, though small in magnitude, still persisted during exercise. The amplitude of the normal circadian rhythm was reduced on exposure to negative air ions. This finding may have implications for the use of ion therapy in the period of transition after crossing multiple time-zones or when moving onto nocturnal work shifts.

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