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Sex-specific features of neuroendocrine and immune responses in women and men during the Ukrainian Antarctic Expedition

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Abstract. We investigated sex-specific features of neuroendocrine, cardiovascular, and immune responses in participants of the Ukrainian Antarctic expeditions during prolonged isolation, as well as in response to acute physical exercise, with a comparative evaluation in women and men. The study included 22 men and 9 women who spent one year at the Ukrainian Antarctic Akademik Vernadsky station, as well as control groups residing in Kyiv. Blood samples were collected before the expedition, quarterly during the stay at the station, and after returning to Kyiv. Serum cortisol, testosterone, and growth hormone levels were measured using enzyme-linked immunosorbent assay (ELISA), while lymphocyte subpopulations were analysed by flow cytometry. A modified Cooper test was used as a model of acute physical exercise to assess physiological responses among expedition candidates. The results showed that cortisol levels increased already in the first quarter of the expedition in participants of both sexes, suggesting activation of the hypothalamic—pituitary—adrenal axis during adaptation to Antarctic conditions. In men, peak cortisol levels were observed at the early stages of the expedition, whereas in women, a more gradual increase was noted, with peak values occurring later in the mission. Testosterone levels increased in both sexes during the expedition; however, after returning to normal conditions, they tended to normalise primarily in men. In women, the increase in heart rate was less pronounced, and recovery of hemodynamic parameters was faster after exertion. The immune response to physical stress also showed sex-related differences: in men, a statistically significant increase in the absolute number of NK cells was observed after exercise, whereas in women these changes were less pronounced; no significant changes in the absolute number of T helper cells were detected in either group. The obtained results indicate that neuroendocrine adaptation to prolonged Antarctic isolation exhibits sex-specific characteristics, but is not associated with evidence of poorer clinical tolerance in women.

Keywords: adaptation, Cooper test, cortisol, neuroendocrine regulation, NK cells, testosterone

1 Introduction

Prolonged human residence in Antarctic conditions represents a unique model for studying physiological adaptation to extreme environments. Polar overwintering combines exposure to low temperatures, an altered photoperiod, restricted social space, and multiple environmental and psychophysiological challenges, all of which require the involvement of complex regulatory mechanisms of the neuroendocrine, cardiovascular, and immune systems. Accumulating evidence suggests that men and women may differ in the mechanisms underlying physiological responses to environmental challenges (Bangasser & Wiersielis, 2018). In particular, sex hormones can modulate the reactivity of the body's regulatory systems, which may influence the nature of adaptive processes under different environmental conditions.

Previously, we demonstrated specific features of immune reactivity and changes in cortisol and testosterone levels in men participating in Ukrainian Antarctic expeditions (Zabara et al., 2021; Dubrovskyi et al., 2025). At the same time, women's physiological responses during prolonged Antarctic isolation remain much less studied. Data on systemic physiological responses in women during polar expeditions are still limited, despite the gradual increase in their participation in polar research. At the same time, accumulating evidence indicates sex-specific patterns of physiological regulation in women, characterised by greater variability and flexibility in regulatory responses, which may contribute to more effective adaptation (Bangasser & Wiersielis, 2018). Such differences are observed at the level of neuroendocrine regulation, cardiovascular reactivity, and immune response. Given the increasing involvement of women in Ukrainian Antarctic expeditions, particularly during wartime, the study of these features is particularly relevant. The aim of this study was to evaluate sex-specific features of neuroendocrine, cardiovascular, and immune responses in participants of Ukrainian Antarctic expeditions during prolonged isolation, as well as in response to acute physical exercise, and to compare these parameters between women and men. Additionally, physiological responses to standardised acute physical exercise were assessed using a modified Cooper test to complement the analysis of adaptive mechanisms.

2 Materials and methods

We investigated the dynamics of hormonal changes among participants of the Ukrainian Antarctic expeditions during a one-year stay at the Akademik Vernadsky station.

2.1 Study site and environmental conditions

The Akademik Vernadsky station is located on a small island in the Southern Ocean, at a considerable visual distance from the Antarctic mainland. The station buildings are situated at an altitude of approximately 8 m above sea level. The climate is maritime, characterised by relatively mild annual temperature variation, with a mean annual temperature of approximately −2 °C. Minimum winter temperatures rarely fall below −20 °C, while maximum summer temperatures seldom exceed +10 °C. The diurnal temperature variation is minimal, often absent, which is typical for maritime climates. The average wind speed is approximately 9 $\mathrm{m \cdot s^{-1}}$, largely due to frequent storm events, particularly during the cold season, when storms may occur on more than 10 days per month. These storms are associated with the passage of cyclones and are accompanied by rapid changes in atmospheric pressure and precipitation. Photoperiod conditions vary markedly across seasons. During the cold season, the duration of the astronomical day decreases to approximately 2 hours, and under conditions of persistent cloud cover, it is perceived as twilight, with solar radiation levels around 10 $\mathrm{W \cdot m^{-2}}$. In contrast, during summer, there is an almost complete absence of darkness, especially under clear-sky conditions, with solar radiation reaching 1000−1200 $\mathrm{W \cdot m^{-2}}$. From November to late December, ultraviolet radiation levels may reach hazardous values due to the episodic influence of the ozone hole.

2.2 Study population

The study included participants of Ukrainian Antarctic expeditions, comprising 22 men and 9 women. The mean age of women was 32.5 ± ± 10.5 years, while the mean age of men was 39.5 ± ± 7.6 years. The overall age range was 22−55 years. All participants were non-obese and were deemed medically fit for Antarctic deployment based on routine pre-expedition medical examinations. Regarding hormonal status, one female participant was in menopause and was therefore excluded from testosterone analysis. Information on the use of hormonal contraception was incomplete and was not included in the analysis.

Serum samples were collected before the expedition (October—November), quarterly during the stay at the station (Q1—Q4), and upon return to Kyiv (April). Pre-expedition measurements were used as individual baseline (reference) values and do not necessarily represent a stress-free physiological state. All blood samples, both in Kyiv and during the expedition, were collected between 08:30 and 10:30 a.m. to minimise the effect of circadian variation. After collection, blood samples were centrifuged, and serum was separated and stored at −80 °C until analysis. During the expedition, samples were stored at controlled temperatures and subsequently transported to Kyiv for further analysis. The control group consisted of healthy adult volunteers (7 men and 8 women) who remained in Kyiv throughout the study period. These participants were mainly laboratory staff who agreed to participate as controls and underwent the same hormonal assessments over a one-year period (2020—2021). The age distribution in the control group was comparable to that of the Antarctic participants, with men being slightly younger and women slightly older; however, these differences were not statistically significant. Immunophenotypic and serological analyses were performed between October 2020 and April 2025. Participants were recruited annually in October—November after routine medical examinations and, additionally, in April following the return from the previous Antarctic expedition. All samples were analysed under identical conditions using a unified study protocol and the same reagent kits. To ensure comparability, samples were analysed within the same enzyme-linked immunoassay run. All participants of the Antarctic expedition involved in the study underwent a medical examination and were deemed fit to work in Antarctica.

2.3 Cooper test

To evaluate general physical fitness and endurance, 36 candidates for Antarctic deployment (24 men and 12 women) performed a modified, circuit-based Cooper test, as described by Zabara et al. (2026). The test comprised four consecutive exercises (push-ups, squat thrusts, abdominal crunches, and squats or squat jumps), performed in repeated cycles at maximal effort within the shortest possible time. The test was designed to assess overall physical performance capacity.

Venous blood was collected after an overnight fast. Blood samples were obtained 30 minutes before and 30 minutes after the test. Immediate post-exercise sampling was avoided due to elevated heart rate and blood pressure; therefore, a 30-minute recovery period was allowed. Blood collection was performed using 21G needles (Sangocan®, KABE LABORTECHNIK, Germany) into serum tubes without anticoagulant (2.6 mL) and lithium-heparin tubes (4.9 mL; Heparin-Li) (Primavette® S and V, KABE LABORTECHNIK, Germany).

2.4 Immunological studies

Lymphocyte subpopulations were analysed by flow cytometry using a Cytomics FC 500 flow cytometer (Beckman Coulter, Brea, CA, USA) according to the previously described methodology (Dons'koi et al., 2019). Immunophenotypic analysis was performed using fluorochrome-conjugated monoclonal antibodies against CD3(A07746), CD4(A07750), CD8(A07757), CD56(A07736), and CD45(A07784) (Beckman Coulter, Brea, CA, USA). Briefly, 100 μL of whole blood was incubated with the corresponding antibodies according to the manufacturer's instructions. After 30 min incubation at room temperature in the dark, red blood cells were lysed using OptiLyse C (Beckman Coulter, Brea, CA, USA Cat. No. A11895), followed by washing with phosphate-buffered saline (PBS) (Sigma-Aldrich, St. Louis, MO, USA). Samples were acquired on a Cytomics FC 500 flow cytometer after appropriate instrument setup, calibration, and compensation. Data analysis was performed using CXP software (Beckman Coulter, Brea, CA, USA). Percentages of lymphocyte subpopulations were calculated within the lymphocyte gate defined by forward- and side-scatter characteristics. Quality control procedures included routine verification of instrument performance, antibody staining, and sample preparation.

2.5 Hormone measurements

Serum cortisol and testosterone levels were determined by enzyme-linked immunosorbent assay (ELISA) using commercially available kits (Xema, Kyiv, Ukraine; cortisol — REF K210, testosterone — REF K209) according to the manufacturer's instructions. Reference ranges for testosterone provided by the manufacturer were: in men aged 20–39 years — 9.0–38 nmol · L^{-1}; 40–55 years — 6.9–21 nmol · L^{-1}; and in men >55 years — 5.9–18.1 nmol · L^{-1}; in women — up to 4.6 nmol · L^{-1}. The analytical performance of the assays was assessed based on manufacturer data. Intra-assay precision (within-run) showed coefficients of variation (CV) ranging from 1.63% to 7.87%, while inter-assay precision (between-run) ranged from 2.57% to 5.25%. Between-run reproducibility demonstrated CV values of 1.72–3.02%. The analytical accuracy of both assays was within ±10% of the expected values.

2.6 Ethical considerations

The study protocol was approved by the Biomedical Ethics Committee of the Institute of Pediatrics, Obstetrics and Gynecology, and by the Clinical Immunology and Allergology Committee of the Ministry of Health of Ukraine. Written informed consent was obtained from all participants prior to inclusion in the study.

2.7 Statistical analysis

Statistical analysis was performed using GraphPad Prism software (GraphPad Software Inc., San Diego, CA, USA). The distribution of continuous variables was assessed using the Shapiro–Wilk normality test. Data are presented as mean ± standard deviation (SD). Changes in parameters over time (baseline *vs* Q1–Q4 and Kyiv) and before/after physical exercise were analysed using paired-sample t-tests for normally distributed data or the Wilcoxon signed-rank test for non-normally distributed data. Comparisons between men and women were performed using unpaired t-tests or the Mann–Whitney U test, as appropriate. For analysis of individual responses, cortisol values were categorised relative to baseline as marked increase (≥2.2-fold) or decrease (>20% below baseline). The frequency of these events between groups was compared using Fisher's exact test. Odds ratios (OR) with 95% confidence intervals (CI) were calculated to estimate the strength of association. Statistical significance was defined as a two-tailed p-value ≤ 0.05.

3 Results

3.1 General tendencies

Baseline cortisol levels before the expedition did not differ between men and women, although there was considerable interindividual variability (Table 1). Therefore, further analysis was performed relative to individual pre-expedition baseline (reference) values. In both sexes, a significant increase in cortisol levels compared with baseline values was already observed during the first quarter of the stay at the station (approximately 1.6× baseline in women and approximately 2.4× in men) (Fig. 1). Relative values were calculated by normalising each individual measurement to their corresponding pre-expedition baseline.

In men, the highest cortisol levels were already recorded in the first quarter, and during this period, they were higher than those observed in women. Subsequently, men showed a gradual decrease. In contrast, women demonstrated a gradual increase in cortisol levels with the duration of their stay at the station, reaching a maximum in the third quarter (approximately 2.4× baseline). During the third and fourth quarters, cortisol levels in women tended to exceed those in men; however, these differences did not reach statistical significance.

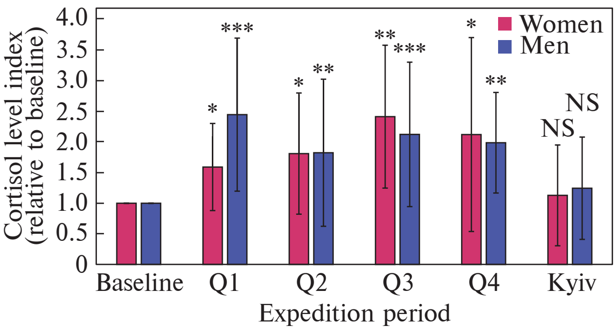

Figure 1. Dynamics of relative cortisol levels in men and women during the Ukrainian Antarctic Expedition. Values are expressed relative to individual baseline levels (baseline = 1) and presented as mean ± SD. Baseline — pre-expedition levels; Q1–Q4 — quarters of the expedition; Kyiv — day of return to Kyiv. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ compared with baseline within the same group (paired t-test). NS — not significant. In the first quarter, cortisol levels were significantly higher in men compared to women ($p = 0.016$). Absolute cortisol concentrations are presented in Table 1. n = 9 (women), n = 22 (men)

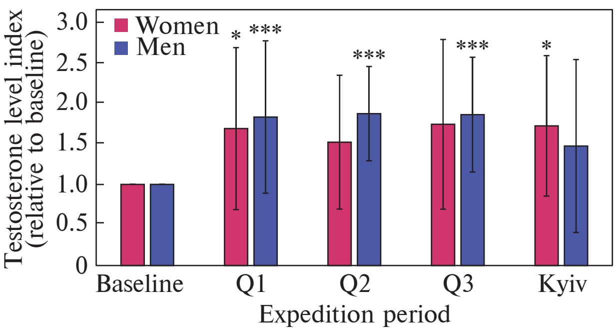

Figure 2. Dynamics of relative testosterone levels in men and women during the Ukrainian Antarctic Expedition. Values are expressed relative to individual baseline levels (baseline = 1) and presented as mean ± SD. Q1–Q3 — quarters of the expedition; Kyiv — day of return to Kyiv. *$p < 0.05$, ***$p < 0.001$ compared with baseline; n = 8 (women), n = 22 (men)

Analysis of absolute values confirmed these trends: cortisol concentrations increased from 253.1 ± 89.6 to 521.8 ± 117.8 nmol · L^{-1} in women (Q3) and from 181.6 ± 87.7 to 402.7 ± 232.0 nmol · L^{-1} in men (Q1), followed by a gradual decline in men and a later peak in women (Table 1).

On the day of return to Kyiv, cortisol levels in both men and women did not differ from baseline, indicating normalisation of hormone levels after completion of the expedition (Fig. 1; Table 1).

Testosterone levels increased in both women and men already during the first quarter of their stay at the station and remained above baseline throughout the expedition (Fig. 2; Table 2). In two women, individual testosterone levels reached clinically significant elevations (>3.8 nmol · L^{-1}). In contrast, in men, although the increase was pronounced, testosterone levels did not exceed clinically significant thresholds. Analysis of absolute values showed that in women, testosterone levels increased from 1.59 ± 0.99 to 2.22 ± 1.56 nmol · L^{-1} in Q1 and remained elevated throughout the expedition, although these changes were not statistically significant (Table 2). In men, testosterone levels increased significantly from 10.29 ± 8.81 to 14.51 ± 11.33 nmol · L^{-1} in Q1 and remained significantly higher than baseline during all subsequent time points (***$p < 0.001$) (Table 2). An important sex-related difference was observed upon return from the expedition. In men, testosterone concentrations decreased from the peak values observed during the expedition and tended to return toward baseline, although they remained significantly higher than pre-expedition levels. In contrast, women maintained elevated testosterone

Table 1. Absolute cortisol concentrations in men and women during the Ukrainian Antarctic Expedition (nmol · L^{-1})

Group	Baseline	Q1	Q2	Q3	Q4	Kyiv
Women	253.1 ± 89.6	384.9 ± 216.1	404.7 ± 162.4*	521.8 ± 117.8***	432.4 ± 206.0*	223.1 ± 127.7
Men	181.6 ± 87.7	402.7 ± 232.0***	292.3 ± 149.3**	347.0 ± 153.3***	332.4 ± 135.1**	203.5 ± 84.4

Note. Values are presented as mean ± SD. Q1–Q4 — quarters of the expedition; Kyiv — day of return to Kyiv. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ compared with baseline within the same group (paired t-test).

concentrations after returning to Kyiv, with no apparent decrease compared with the third quarter of the expedition (Fig. 2; Table 2).

Overall, hormonal changes during the Ukrainian Antarctic Expedition demonstrated pronounced individual variability. In most participants, cortisol and testosterone levels increased during the expedition, although in some individuals a decrease in these hormones was also observed. A more comprehensive understanding of these processes requires studies with larger sample sizes. Nevertheless, in the present work, an individualised analysis of hormonal dynamics was performed.

3.2 Individual changes

We analysed individual changes in cortisol levels during the Ukrainian Antarctic Expedition in women and men. A marked increase in cortisol levels was observed significantly more often in men. Specifically, in men, ≥2.2-fold increases in cortisol relative to baseline were detected in 41.3% (31/75) of samples collected during the stay at the station, whereas in women such increases occurred significantly less frequently — 21% (8/38) of cases (Odds ratio = 4.35, 95% CI = 1.34–14.08, $p = 0.012$). No such increases were observed in the control groups of men and women (Fig. 3).

A decrease in cortisol levels (>20% below baseline) during the expedition was more frequently observed in women — 23.6% (9/38) of cases compared with 6.6% (5/75) in men ($p = 0.0127$). However, similar decreases were also observed in the control group of women who remained in Kyiv throughout the year, with 25% (2/8) of cases showing decreases. No such changes were detected in the control group of men (Fig. 3).

3.3 Adaptation success

According to the expedition physician's reports, women did not report health complaints more frequently than men. The number of individuals with signs of complicated adaptation (more than three complaints per month) was even lower among women; however, this difference did not reach statistical significance. In half of the female participants, menstrual cycle disturbances were observed during the second half of the stay

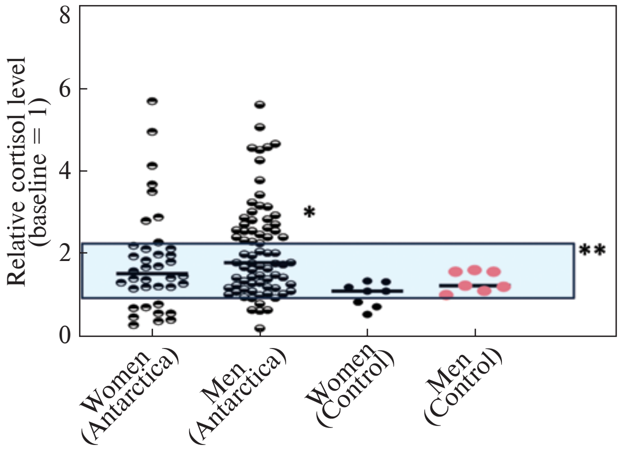

Figure 3. Individual cortisol responses relative to baseline in women and men during the Ukrainian Antarctic Expedition and in control groups. Ovals represent individual samples; horizontal bars indicate group means. Each point represents an individual measurement obtained during the expedition period (Q1–Q4). The shaded area indicates the range between a 20% decrease (0.8× baseline) and a twofold increase (2.2× baseline). * 2.2 increase in cortisol occurred more frequently in men than in women (Odds ratio = 4.35, 95% CI = 1.34–14.08, $p = 0.012$). ** Decrease in cortisol >20% from baseline occurred more frequently in women than in men during the expedition ($p = 0.0127$)

Table 2. Absolute testosterone levels (nmol · L^{-1}) in men and women during the Ukrainian Antarctic Expedition

Group	Baseline	Q1	Q2	Q3	Kyiv
Women	1.59 ± 0.99	2.22 ± 1.56	2.01 ± 1.34	2.22 ± 1.53	2.32 ± 1.29
Men	10.29 ± 8.81	14.51 ± 11.33***	16.61 ± 13.34***	15.70 ± 12.04***	12.21 ± 6.09***

Note. Data are presented as mean ± SD. Q1–Q3 — quarters of the expedition; Kyiv — day of return to Kyiv. Statistical significance was assessed relative to baseline values: ***$p < 0.001$; n = 8 (women), n = 22 (men).

at the station or after returning from the expedition. In one case, the cycle recovered after approximately three months.

3.4 Cooper test

Women generally performed the Cooper test more successfully. Only 1 of 14 women did not complete the test within the allotted time, whereas among men, 12 of 34 participants failed to complete the test. In two men, systolic blood pressure exceeded 160 mmHg five minutes after exercise. In addition, three men experienced adverse reactions during the second blood sampling (one case of brief loss of consciousness lasting approximately one minute, one case of vomiting, and one case of pronounced nausea). In two women, nausea was observed during the first blood sampling; however, their condition did not worsen during the second sampling.

For further analysis, only the participants who completed the test were included. No significant differences were found between women and men in age, body weight, BMI, blood pressure, or heart rate before the test. Baseline cortisol levels also did not differ between the groups. The average test completion time did not differ significantly, although women completed the course approximately 40 seconds later (5.21 min *vs* 4.42 min).

After exercise, the increase in heart rate was less pronounced in women: the mean heart rate was 156 beats · min^{-1} compared with 166 beats · min^{-1} in men, although this difference did not reach statistical significance. Five minutes after completing the test, women demonstrated lower systolic blood pressure (120 mmHg) and heart rate (103 beats · min^{-1}) than men (133 mmHg and 119 beats · min^{-1}, respectively; $p = 0.043$ and $p = 0.037$, respectively). Individual analysis showed that, after the Cooper test, heart rate increased by 67 beats · min^{-1} on average in women and 83 beats · min^{-1} in men ($p = 0.03$). Five minutes after exercise, heart rate remained elevated above baseline by 13.5 beats · min^{-1} in women and by 36.8 beats · min^{-1} in men ($p = 0.006$).

3.5 Immunoendocrine changes

The increase in cortisol levels after the Cooper test was similar in women and men, both on average and at the individual level. In women, cortisol levels increased on average 1.77-fold after exercise, whereas in men the increase was 1.56-fold.

Before the test, men exhibited significantly higher proportions of Natural killer (NK) cells ($CD3^-CD56^+$) and lower proportions of T helper cells ($CD3^+CD4^+$) compared with women (Fig. 4a). After physical exercise, men demonstrated a pronounced increase in the proportion of NK cells, accompanied by a decrease in T helper cells. In women, the changes followed the same direction; however, they were less pronounced, with a smaller increase in NK cells and a less marked decrease in T helper cells (Fig. 4b). Analysis of absolute values showed that in women, changes in T helper cell counts (925.79 → 831.82) and NK cell counts (229.33 → 251.73) were not statistically significant (Table 3). In men, despite no significant change in T helper cell counts (867.19 → 833.05), a significant increase in NK cell counts was observed (313.84 → 484.84; $p = 0.0008$) (Table 3).

Table 3. Absolute counts of immune cell populations before and after the Cooper test

Group	Parameter	Before	After	p-value
Women	T helper cells ($CD3^+CD4^+$), abs	925.79	831.82	0.241
	NK cells ($CD3^-CD56^+$), abs	229.33	251.73	0.337
Men	T helper cells ($CD3^+CD4^+$), abs	867.19	833.05	0.289
	NK cells ($CD3^-CD56^+$), abs	313.84	484.84	**0.0008**

4. Discussion

4.1 Hypothalamic–pituitary–adrenal axis and hormonal adaptations

A prolonged stay in Antarctica is associated with chronic exposure to multiple environmental and psychophysiological challenges, including social isolation, environmental confinement, disruption of the photoperiod, and extreme climatic conditions. In this context, the term "stress" refers to integrated psychophysiological responses associated with prolonged exposure to the Antarctic environment, encompassing neuroendocrine, immune, and cardiovascular adaptations rather than isolated psychological stress. These factors are associated with alterations in hypothalamic–pituitary–adrenal (HPA) axis activity and variability in cortisol secretion, a key hormone of the stress response (Spinelli & Werner Junior, 2022). In this context, the obtained results suggest that cortisol dynamics during the expedition may exhibit a phase-dependent pattern and differ between men and women. In particular, men showed a more pronounced response during the early stages of the stay, whereas in women the changes were more gradual and variable, which may reflect differences in HPA axis regulation under prolonged exposure to extreme conditions.

Despite the observed increase in cortisol levels, these changes cannot be unequivocally interpreted as markers of increased psychological stress. Similar findings have been reported in other Antarctic studies, where elevated cortisol concentrations were not accompanied by increased subjective stress (Strewe et al., 2019). Consistent with this, European studies have not demonstrated evidence of sustained HPA axis hyperactivation during prolonged isolation. In particular, Gifford et al. (2019) did not observe significant changes in basal cortisol levels during an Antarctic expedition. More recent data further indicate that circadian rhythms of cortisol secretion may be preserved even during prolonged physical exertion and under altered photoperiod, although elevated morning levels may occur (Gifford et al., 2025). In this context, changes in cortisol likely reflect adaptive neuroendocrine adjustments associated with physical activity, energy balance, and environmental conditions rather than psychological stress alone.

Circadian organisation likely plays an important role in shaping these responses. As demonstrated in recent studies, the diurnal rhythm of cortisol secretion may be maintained even under polar conditions, although its amplitude and phase characteristics may be altered (Gifford et al., 2025). In this context, variations in cortisol levels may reflect adaptation to altered photoperiod, sleep patterns, and physical activity. Sleep quality is another important factor influencing HPA axis activity. It is often impaired under Antarctic conditions (Moraes et al., 2023), which may con-

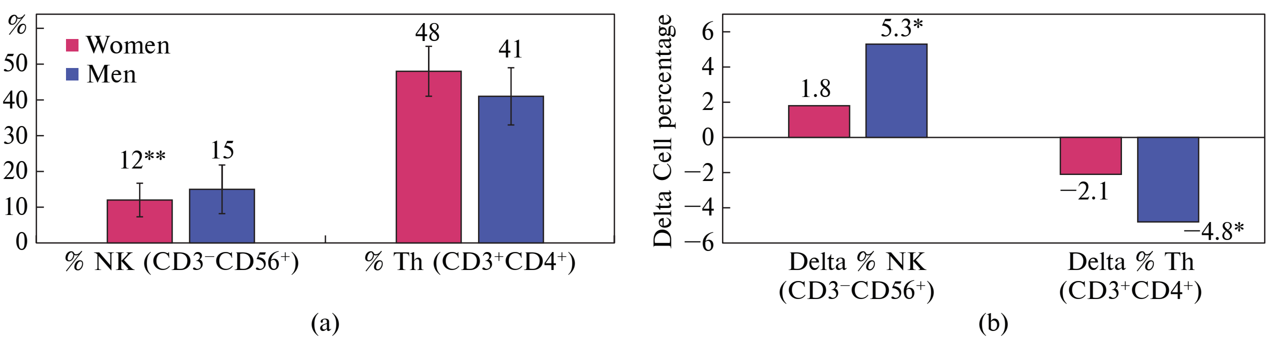

Figure 4. Immune cell distribution and changes after the Cooper test in women and men. (a) Baseline percentages of NK cells ($CD3^-CD56^+$) and T helper cells ($CD3^+CD4^+$). (b) Changes in immune cell percentages (delta, post-exercise minus baseline). Data are presented as mean ± SD. **$p < 0.01$ between groups (men vs women) in panel a; *$p < 0.05$ between groups in panel b

tribute to circadian disruption and associated neuroendocrine changes. The concept of allostatic load is also relevant when assessing long-term exposure to extreme conditions; however, the absence of persistent post-expedition changes in cortisol levels may suggest a lack of pronounced long-term dysregulation of the HPA axis (Guidi et al., 2020).

Overall, the obtained results suggest that in women, adaptation to prolonged Antarctic isolation may be associated with more gradual and variable hormonal changes within the HPA axis. At the same time, these differences should be interpreted with caution, as the study did not include validated psychological stress assessment tools or a comprehensive evaluation of neuroendocrine regulation.

Adaptation to Antarctic conditions is not limited to cortisol changes but may also involve other hormonal systems. Changes in testosterone levels observed during the expedition may reflect the involvement of the hypothalamic–pituitary–gonadal (HPG) axis in adaptive processes. It is well established that the interaction between the HPA and HPG axes is bidirectional, and chronic stress may modulate gonadal function through central regulatory mechanisms (Joseph & Whirledge, 2017).

Testosterone responses to stress are heterogeneous. While suppression of gonadal function under chronic psychological stress is well documented, some studies report stable or even increased androgen levels in response to physical or mixed stressors (Crewther et al., 2016). In this context, the observed changes may reflect adaptive responses to the combined effects of isolation, physical activity, and sustained functional load.

Sex differences in hormonal dynamics following stress exposure require careful interpretation. The reversibility of changes observed in men may suggest preserved regulatory flexibility of the HPG axis. In contrast, the persistence of altered testosterone levels in some women may reflect a more prolonged course of hormonal adjustment or differences in post-stress endocrine regulation. However, these interpretations are limited by the absence of measurements of gonadotropins and other steroid hormones, which precludes a comprehensive assessment of HPG axis function. Given that baseline androgen levels in women are substantially lower than in men, even moderate fluctuations may have relatively greater physiological relevance. Nevertheless, these changes cannot be interpreted as evidence of pathological hyperandrogenism and are more appropriately considered within the range of physiological variability.

Menstrual disturbances observed during the expedition may be associated with the combined effects of stress, altered photoperiod, circadian disruption, and changes in energy balance. Disruption of light exposure and circadian rhythms is known to affect central neuroendocrine regulation and has been linked to menstrual irregularities (Shao et al., 2021). However, the available data do not allow for establishing a causal relationship between testosterone changes and menstrual disturbances, and this association should therefore be interpreted with caution.

Overall, hormonal changes during the Ukrainian Antarctic Expedition were characterised by substantial interindividual variability. Although most participants demonstrated a general tendency toward increased cortisol and testosterone levels, opposite trends were observed in some individuals, reflecting individual differences in neuroendocrine responses to prolonged exposure to extreme conditions.

Importantly, the present data do not provide evidence that the observed hormonal patterns in women were associated with poorer clinical tolerance to expedition-related stress. According to available medical observations, the frequency of reported health complaints in women did not exceed that in men, and the number of individuals with signs of complicated adaptation was even lower, although these differences were not statistically significant. However, this observation should be interpreted with caution, as the study did not include validated stress assessment tools or standardised clinical evaluation of adaptation.

Overall, the results indicate that the neuroendocrine response to prolonged Antarctic exposure is characterised by variable and context-dependent changes in individual hormonal parameters. However, given the limited set of measured markers, these data do not allow conclusions regarding an integrated reorganisation of regulatory systems or the existence of distinct adaptive strategies. The observed sex-related differences should therefore be interpreted as differences in the measured parameters rather than as indicators of different levels of stress burden or fundamentally different mechanisms of adaptation.

4.2 Response to acute physical stress (Cooper test) and immunoendocrine interactions

To complement the findings from the Antarctic expedition, the response to acute physical stress was also assessed using the Cooper test. This approach allows extending the interpretation of the data by considering not only baseline hormonal parameters but also the integrated physiological response to physical load.

Cardiovascular and autonomic response to physical load. The response to acute physical stress provides additional insight into sex-specific aspects of physiological regulation, particularly in the context of autonomic and neuroendocrine interactions. Differences in cardiovascular responses to physical exertion are known to be influenced by both behavioural and physiological factors, including pacing strategies and perception of effort. At the same time, these differences may reflect fundamental features of autonomic regulation of the cardiovascular system. Acute physical exertion is associated with activation of the sympathetic nervous system, leading to increases in heart rate and blood pressure, followed by a gradual return to baseline mediated by parasympathetic reactivation. The rate of heart rate recovery after exercise is considered an important indicator of autonomic function and cardiovascular reserve (Peçanha et al., 2014), and its impairment has been associated with increased risk of cardiovascular and all-cause mortality (van de Vegte et al., 2018).

The obtained results may suggest more efficient recovery of autonomic regulation in women, potentially reflecting relatively higher parasympathetic tone and a more balanced interaction between sympathetic and parasympathetic activity. Similar sex-related differences have been described in the literature: women of reproductive age generally demonstrate greater vagal modulation both at rest and during recovery after exercise (Koenig & Thayer, 2016). Estrogens may further contribute to these effects through modulation of vascular tone, β-adrenergic sensitivity, and baroreflex function, thereby resulting in more stable hemodynamic responses during and after physical exertion. In contrast, men more often exhibit a stronger sympathetic response to stress (Liu & Zhang, 2020). At the same time, the observed differences may be influenced not only by sex-related regulatory features but also by physical fitness levels and individual characteristics of the participants.

Hormonal factors may also modulate the integrated response to physical stress. In particular, activation of the HPA axis during exercise contributes to the mobilisation of energy resources and maintenance of vascular tone through interactions with catecholaminergic systems. In this context, differences in HPA axis reactivity may influence the overall cardiovascular response to stress (Bangasser & Wiersielis, 2018).

Overall, the obtained data may indicate that differences in recovery after physical exertion are associated not only with physical fitness but also with features of autonomic and neuroendocrine regulation. However, these findings should be interpreted with caution, as they are based on a limited set of physiological parameters and do not include a comprehensive assessment of functional status. In the context of preparation for Antarctic expeditions, the ability to efficiently restore hemodynamic stability after acute stress may be considered a potential, but not exhaustive, indicator of adaptive capacity.

Immune response to acute physical stress. Sex differences in immune responses to acute physical stress may reflect specific features of neuroendocrine–immune interactions. It is well established that acute physical exertion activates both the hypothalamic–pituitary–adrenal (HPA) axis and the sympathoadrenal system, resulting in increased levels of cortisol and catecholamines and, consequently, modulation of immune function. Short-term intense exercise typically induces transient mobilisation of innate immune cells, particularly NK cells, primarily through adrenergic mechanisms (Campbell & Turner, 2018). Glucocorticoids, in turn, may influence the balance between innate and adaptive immunity by modulating T helper cell proliferation, differentiation, and cytokine activity (Cain & Cidlowski, 2017).

The results should be interpreted with consideration of absolute cell counts. A statistically significant increase in the absolute number of NK cells after physical exertion was observed only in men, whereas in women, this trend did not reach statistical significance. This may indicate a more pronounced mobilisation of innate immune cells in men, while in women the response may be less intense or more variable.

In contrast, no significant changes in the absolute number of T helper cells were detected in either group. Therefore, the observed changes in relative immune cell proportions are likely driven primarily by alterations in the NK cell population rather than by a coordinated redistribution between innate and adaptive immune compartments. In this context, the data may suggest that the response to acute physical stress is predominantly innate, with sex-related differences reflecting the magnitude of this response rather than fundamentally distinct regulatory mechanisms.

It should also be taken into account that the direction and magnitude of immune changes are determined not only by circulating hormone levels but also by cellular sensitivity to glucocorticoids and catecholamines, receptor expression, and intracellular signaling pathways. In addition, sex hormones may modulate immune responses through effects on cytokine networks and immune cell function (Taneja, 2018), potentially leading to different immunological outcomes even under similar endocrine conditions.

The balance between NK cells and T helper cells may be considered an integrated indicator of immune regulation; however, within the present study, this assessment remains limited. Similar immune profiles have been described in other physiological contexts and may reflect general mechanisms of stress response (Dons'koi et al., 2020; 2023). In a broader context, these findings complement the observations obtained during the Antarctic expedition, indicating that sex-related differences may be manifested not only at the level of baseline hormonal parameters but also in the responses to acute physical stress. At the same time, these conclusions should be considered preliminary, given the limited scope of immunological parameters assessed.

4.3 Limitations of the study

This study has several limitations that should be considered when interpreting the results. First, the relatively small number of female participants limits the statistical power for sex-specific analyses. In addition, information on hormonal contraception was incomplete and was not included in the analysis, which may have influenced the interpretation of hormonal variability in female participants. Furthermore, one postmenopausal participant was excluded from testosterone analysis, resulting in a further reduction of the sample size for this parameter.

Second, the assessment of stress was limited, as the study did not include validated psychological instruments such as standardised questionnaires (*e.g.*, the Perceived Stress Scale) and relied primarily on physiological biomarkers (cortisol) and a limited set of additional biochemical markers (*e.g.*, ACTH and DHEA-S were not assessed). Therefore, the interpretation of "stress-related" adaptations reflects primarily physiological endocrine responses rather than a comprehensive psychometric evaluation of perceived stress.

Third, anticipatory stress prior to the expedition cannot be fully excluded, and baseline measurements may have been influenced by pre-expedition psychological factors.

Finally, information regarding participants' prior tolerance to blood collection was not collected, which may have affected the interpretation of physiological responses during sampling procedures. Additionally, acute procedural and exercise-related stress may have affected cortisol levels during the second sampling session. Nevertheless, syncopal episodes occurred after completion of blood collection, reducing the likelihood of a substantial impact on the cortisol measurements.

5 Conclusions

The present study demonstrated substantial inter-individual variability in neuroendocrine, cardiovascular, and immune responses during the Ukrainian Antarctic Expedition, reflecting heterogeneous physiological adaptation to prolonged exposure to extreme environmental conditions.

Sex-related differences were observed in hormonal, cardiovascular, and immune responses to physical stress. Women demonstrated a more gradual pattern of hormonal changes and less pronounced cardiovascular and immune responses to acute exercise compared with men. However, the findings do not indicate poorer tolerance to expedition-related stress in women.

Overall, the results support the importance of individualised biomedical monitoring during long-term Antarctic missions. Further studies incorporating comprehensive hormonal, immunological, and standardised psychological stress assessment are required to better understand adaptation mechanisms under extreme environmental conditions.

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Conflict of Interest. The authors declare no conflict of interest.

References

Bangasser, D. A., & Wiersielis, K. R. (2018). Sex differences in stress responses: A critical role for corticotropin-releasing factor. *Hormones (Athens), 17*(1), 5–13. https://doi.org/10.1007/s42000-018-0002-z

Cain, D. W., & Cidlowski, J. A. (2017). Immune regulation by glucocorticoids. *Nature Reviews Immunology, 17*(4), 233–247. https://doi.org/10.1038/nri.2017.1

Campbell, J. P., & Turner, J. E. (2018). Debunking the myth of exercise-induced immune suppression: Redefining the impact of exercise on immunological health across the lifespan. *Frontiers in Immunology, 9*, 648. https://doi.org/10.3389/fimmu.2018.00648

Crewther, B. T., Kilduff, L. P., Finn, C., Scott, P., & Cook, C. J. (2016). Salivary testosterone responses to a physical and psychological stimulus and subsequent effects on physical performance in healthy adults. *Hormones* (*Athens*), *15*(2), 248–255. https://doi.org/10.14310/horm.2002.1676

Dons'koi, B. V., Baksheev, S. M., Sudoma, I. O., Palyha, I. E., Khazhylenko, K. G., Zabara, D. V., Anoshko, Y. I., Dosenko, V. E., & Dubrovsky, E. I. (2023). A blinded investigation: Accentuated NK lymphocyte CD335 (NKp46) expression predicts pregnancy failures. *Diagnostics, 13*(11), 1845. https://doi.org/10.3390/diagnostics13111845

Dons'koi, B. V., Osypchuk, D. V., & Chernyshov, V. P. (2019). Enumeration of peripheral blood NKp46 positive NK lymphocytes reflects NK cytotoxic activity *in vitro*. *Journal of Immunological Methods, 474*, 112639. https://doi.org/10.1016/j.jim.2019.112639

Dons'koi, B. V., Tutchenko, T. M., Chernyshov, V. P., & Stepaniuk, K. S. (2020). HCMV seropositivity is associated with specific proinflammatory immune phenotype in women with implantation failure. *Immunology Letters, 217*, 84–90. https://doi.org/10.1016/j.imlet.2019.11.008

Dubrovskyi, I., Zabara, D., Anoshko, Y., Kozeretska, I., Deyneka, I., Khytryi, A., Matkovskyi, V., Martynenko, D., & Dons'koi, B. (2025). Immune accentuations as a prognostic factor for adaptation in Antarctic conditions. *Polar Biology, 48*, 53. https://doi.org/10.1007/s00300-025-03359-9

Gifford, R. M., O'Leary, T., Cobb, R., Blackadder-Weinstein, J., Double, R., Wardle, S. L., Anderson, R. A., Thake, C. D., Hattersley, J., Imray, C. H. E., Wilson, A., Greeves, J. P., Reynolds, R. M., & Woods, D. R. (2019). Female reproductive, adrenal, and metabolic changes during an Antarctic traverse. *Medicine & Science in Sports & Exercise*, *51*(3), 556–567. https://doi.org/10.1249/MSS.0000000000001803

Gifford, R. M., Taylor, N., Kendall, J., Hattersley, J., Homer, N. Z. M., Woods, D. R., Imray, C., & Wilson, A. J. (2025). Preserved circadian variation in cortisol and androgens during a ski traverse of Antarctica in summer. *Scientific Reports*, *15*, 17726. https://doi.org/10.1038/s41598-025-01165-1

Guidi, J., Lucente, M., Sonino, N., & Fava, G. A. (2020). Allostatic load and its impact on health: A systematic review. *Psychotherapy and Psychosomatics, 90*(1), 11–27. https://doi.org/10.1159/000510696

Joseph, D. N., & Whirledge, S. (2017). Stress and the HPA axis: Balancing homeostasis and fertility. *International Journal of Molecular Sciences, 18*(10), 2224. https://doi.org/10.3390/ijms18102224

Koenig, J., & Thayer, J. F. (2016). Sex differences in healthy human heart rate variability: A meta-analysis. *Neuroscience & Biobehavioral Reviews, 64*, 288–310. https://doi.org/10.1016/j.neubiorev.2016.03.007

Liu, Q., & Zhang, W. (2020). Sex differences in stress reactivity to the Trier Social Stress Test in virtual reality. *Psychology Research and Behavior Management, 13*, 859–869.

Moraes, M. M., Marques, A. L., Borges, L., Hatanaka, E., Heller, D., Núcez-Espinosa, C. A., Gonçalves, D. A. P., Soares, D. D., Wanner, S. P., Mendes, T. T., & Arantes, R. M. E. (2023). Sleep impairment and altered pattern of circadian biomarkers during a long-term Antarctic summer camp. *Scientific Reports*, 13(1), 15959. https://doi.org/10.1038/s41598-023-42910-8

Peçanha, T., Silva-Júnior, N. D., & de Moraes Forjaz, C. L. (2014). Heart rate recovery: autonomic determinants, methods of assessment and association with mortality and cardiovascular diseases. *Clinical Physiology and Functional Imaging, 34*(5), 327–339. https://doi.org/10.1111/cpf.12102

Shao, S., Zhao, H., Lu, Z., Lei, X., & Zhang, Y. (2021). Circadian rhythms within the female hypothalamic–pituitary–gonadal axis: From physiology to etiology. *Endocrinology, 162*(8), bqab117. https://doi.org/10.1210/endocr/bqab117

Spinelli, E., & Werner Junior J. (2022). Human adaptative behavior to Antarctic conditions: A review of physiological aspects. *WIREs Mechanisms of Disease, 14*(5), e1556. https://doi.org/10.1002/wsbm.1556

Strewe, C., Moser, D., Buchheim, J.-I., Gunga, H.-C., Stahn, A., Crucian, B. E., Fiedel, B., Bauer, H., Gössmann-Lang, P., Thieme, D., Kohlberg, E., Choukèr, A., & Feuerecker, M. (2019). Sex differences in stress and immune responses during confinement in Antarctica. *Biology of Sex Differences*, *10*, 20. https://doi.org/10.1186/s13293-019-0231-0

Taneja, V. (2018). Sex hormones determine immune response. *Frontiers in Immunology, 9*, 1931. https://doi.org/10.3389/fimmu.2018.01931

van de Vegte, Y. J., van der Harst, P., & Verweij, N. (2018). Heart rate recovery 10 seconds after cessation of exercise predicts death. *Journal of the American Heart Association, 7*(8), e008341. https://doi.org/10.1161/JAHA.117.008341

Zabara, D., Kozeretska, I., Deineko, I., Anoshko, Y., Shapovalenko, N., Stamboli, L., & Dons'koi, B. (2021). Immune factors and health of Antarctic explorers. *Ukrainian Antarctic Journal,* (*2*), 94–105. https://doi.org/10.33275/1727-7485.2.2021.680

Zabara, D., Kozeretska, I., Klapoushenko, I., Anoshko, Y., Dubrovskyi, I., & Dons'koi, B. (2026). Lymphocyte subpopulations in healthy Ukrainian men: Local reference ranges, long temporal stability, and exercise-induced variability. *Immunobiology*, *231*(2), 153170. https://doi.org/10.1016/j.imbio.2026.153170

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Статево-специфічні особливості нейроендокринних та імунних реакцій у жінок та чоловіків під час Української антарктичної експедиції

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Реферат. Метою роботи було дослідити особливості нейроендокринної, серцево-судинної та імунної відповіді в учасників Українських антарктичних експедицій під час тривалого перебування в умовах ізоляції та у відповідь на гострий фізичний стрес із порівняльною оцінкою відповідних показників у чоловіків та жінок. У дослідження було включено 22 чоловіка та 9 жінок, які перебували на Українській антарктичній станції «Академік Вернадський» протягом року, а також контрольні групи у Києві. Зразки крові відбирали перед експедицією, щоквартально під час перебування на станції та після повернення до Києва. Рівні кортизолу, тестостерону та соматотропного гормону визначали методом імуноферментного аналізу (ELISA), субпопуляції лімфоцитів — методом проточної цитометрії. Для оцінки фізіологічних реакцій на гостре фізичне навантаження у кандидатів експедиції було використано модифікований тест Купера. Результати показали, що рівень кортизолу підвищувався вже в першому кварталі експедиції в учасників обох статей, що свідчить про активацію гіпоталамо-гіпофізарно-надниркової осі під час адаптації до антарктичних умов. У чоловіків максимальні значення кортизолу спостерігалися на ранніх етапах експедиції, тоді як у жінок відзначалася більш поступова динаміка гормональної відповіді з максимумом у пізніші періоди перебування. Рівні тестостерону підвищувалися у представників обох статей, однак після повернення до звичних умов нормалізувалися переважно у чоловіків. Реакція серцево судинної системи на фізичне навантаження у жінок характеризувалася менш вираженим підвищенням частоти серцевих скорочень і швидшим відновленням гемодинамічних показників. Імунна відповідь на фізичний стрес також мала статеві особливості: у чоловіків частіше спостерігалося збільшення абсолютної кількості NK-клітин, тоді як у жінок подібні зміни були менш вираженими. Для жодної групи не було відмічено значних змін рівня Т-хелперів. Отримані результати свідчать, що нейроендокринна адаптація до умов тривалої антарктичної ізоляції має свої особливості для різних статей, однак не супроводжується ознаками гіршої клінічної переносимості для жінок.

Ключові слова: NK-клітини, адаптація, кортизол, нейроендокринна регуляція, тест Купера, тестостерон