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LIGHTING CHARACTERISTICS DURING THE POLAR DAY AND THEIR IMPACT ON CHANGES IN MELATONIN SECRETION

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Abstract

People traveling between climate zones can be exposed to extreme environmental stimuli which significantly differ from their place of habitual residence. A move from the temperate climate of Central Europe to the subpolar climate of northern Europe means exposure to great changes in two climate parameters: lighting and biothermal characteristics. The sudden change of solar radiation, temperature, wind and humidity, force the organism to undergo intensive adaptation processes. While the change in lighting conditions involves a diurnal rhythm adaptation of the physiological clock (regulated by the hormone melatonin), the change of biothermal factors (represented by *UTCI*) produce additional stress on the strongly loaded human organism. The field experiment was carried out in Poland and Norway so the impact of the selected radiation stimuli on melatonin production could be carried out in conditions of natural constant lighting. The paper presents the results of the preliminary analysis of our research conducted from 22 May to 12 June 2011. The distribution of daily outdoor photosynthetically active radiation (PAR) intensity, which is a spectral distribution of solar visible radiation in selected times of the day were analyzed. Lighting conditions surrounding each subject (doses of reached energy of visible solar radiation and illumination intensity) were examined as well. Additional adaptation stress caused by different biothermal conditions (expressed by *UTCI* index) was also taken into consideration. Diurnal melatonin concentrations were determined in saliva samples.

Key words

UTCI • adaptation • diurnal rhythm • lighting conditions • melatonin (MEL) • polar day

Introduction

Melatonin (MEL) is the main hormone produced by the pineal gland. This gland is a part of the thalamus and localized in a central part of the human brain (Karasek 1997). The melatonin hormone activates and stimulates the endogenous biological clock. This clock controls many of the physiological cycles in the human body (Zawilska et al. 2009; Skwarło-Sońta & Piesiewicz 2010). It is well known that light has the biggest impact on the functioning of the pineal gland. Melatonin is often called a 'dark hormone' because it is produced mainly during the dark period.

Large inter-individual and regional differentiations of MEL concentration in humans were found in previous studies. These studies show that not only the occurrence of light stimuli resulting from a photoperiod affects MEL production, but the type and characteristics of this stimulus as well as the time of its occurrence is important (Morita et al. 1998, 2002). What still needs to be examined is which characteristic of lighting (artificial and/or natural) mainly affects the observed melatonin concentrations and the typical diurnal rhythm of those melatonin concentrations.

Clinical studies have shown that the melatonin rhythm is characteristic and constant for a given person and can be used as an indicator to assess the person's state of health (Skwarło-Sońta 2008). The inter-individual rhythm of melatonin secretion is probably the result of the adaptation to local environmental (mainly lighting) conditions. This finding is confirmed by regional and seasonal differences of MEL concentration occurring among Polish, Japanese and Vietnamese populations (Błażejczyk et al. 2005; Maroszek et al. 2010). There are no reports of the possible influence of biothermal conditions on MEL secretion in people. Therefore, to investigate which lighting characteristics have the biggest impact on MEL rhythm modifications, it is important to investigate personal MEL profiles in the different lighting (mixed: artificial and natural). Radiation conditions to which the subject is adapted (place of permanent residence) and not adapted (different lighting zone) also must be taken into consideration.

Additional adaptation stress in subjects caused by actual biothermal conditions, influences the functioning of the human organism and can disturb its circadian rhythm (de Freitas & Grigorieva 2010; Błażejczyk 2011).

The purpose of the present paper is to discuss the preliminary results of the field experiment conduced in May/June 2011, in Poland (Warsaw) and Norway (Tromso). The aim of the experiment was to see if sudden changes of environmental conditions without changes in the time zone, influence the circadian rhythm of melatonin.

Materials and methods

In the experiment eight Polish volunteers (age 23-26, both sexes) were involved. The whole experiment session lasted 21 days. The first 5 days, the subjects spent in their place of habitual residence in Warsaw, Poland. The 6th day the volunteers were transferred to Tromso (70°N, Norway) where they stayed for 7 days. On the 14th day they returned to Warsaw. The last 7 days of the experiment, the volunteers spent in their place of habitual residence.

In this field experiment, three types of measurements were done:

1) measurements of meteorological and spectroradiometer outdoor surveys,

2) individual measurements of environmental characteristics of the subject's surroundings,

3) measurements of melatonin concentration in saliva samples.

Meteorological parameters were registered automatically every minute: intensity of global 0.4-3.0 μm and visible 0.4-0.76 μm solar radiation, wind speed as well as air temperature and humidity. All these meteorological measurements were taken by the HOBO Micro Station. Additionally, spectral characteristics of solar light (irradiation, CCT, peak wave length, light intensity) were reordered several times a day by using LightSpex (GretagMacbeth). The activity level of each participant and the light intensity in the surroundings were reordered with the use of ActiWatch (Mini Mitter Company Inc). The spectral characteristics of visible radiation doses the subjects were exposed to, were controlled in 7 spectral ranges by HandyLight (Biotex).

Measured meteorological variables were used to calculate *UTCI* values which characterized biothermal conditions in the examined areas. The new Universal Thermal Climate Index measures biothermal conditions (Bröde et al. 2012). The Index precisely indicates environmental stress involving particular physiological reactions in subjects (see articles in the current issue Błażejczyk et al. 2013; Bröde et al. 2013).

Saliva samples were collected at 4h intervals, beginning at 11:00, with subsequent sampling times at 15:00, 19:00, 23:00 and 03:00, 07:00. Samples were collected into Salivette (Sardstedt) collection tubes and then were analyzed by using RIA (*Radio Immuno Assay*). Melatonin peak and the time of its occurrence were found by using Spline software, based on Gauss interpolation.

Results

The intensity of photosynthetically active radiation (PAR, 400-710 nm) measured in Warsaw on May 25, 2011 (control sampling day) and in Tromso was found to be statistically significant. In the morning and at noon until 6 pm, a higher intensity of PAR radiation was observed in Warsaw. During the evening and at night time, the intensity of PAR in Tromso was from 10 to 50 times higher than in Warsaw (Fig. 1).

No significant differences in the spectral distribution of incoming solar radiation were noted among the locations on the days which were compared. In the morning, at 7 am in both places, the maximum energy occurred in a wavelength of 535 nm, and at 11 am in a wavelength of 480 nm. Small differences were observed in the afternoon and evening hours (Fig. 2).

Similar spectral characteristics of visible radiation in Warsaw and Tromso are an effect of the similar cloud cover and air humidity observed at both locations (Tab. 1).

Regarding biothermal conditions, we have found that *UTCI* values calculated for the noon period (12 UTC) were different in the studied locations and periods. The conditions intensified adaptation stress in subjects. On control sampling day (25 May) in Warsaw, meteorological conditions were perceived as a 'comfort' and did not cause any thermal stress at thermoregulation system (*UTCI* 14.6°C). At the beginning of the stay in Tromso (May 28-June 3, 2011), a mean *UTCI* value of 3.5°C indicated slight cold stress. At the end of the stay, moderate cold stress occurred (*UTCI* of -4.9 and -0.3°C). In Tromso, thermoneutral conditions were observed (*UTCI* of 10.9°C) only on the 6th day. After returning to Warsaw (June 5-11, 2011), the thermoregulatory systems of the volunteers were exposed to daily changes in the stress category, from 'no thermal stress' on the first day to 'moderate heat stress' (*UTCI* of 27.2-28.4°C) on the 4th and 5th day, respectively. Such great changes and variations in biothermal conditions and significant adaptation stress factors which can influence functioning of circadian rhythm in examined subjects, must be taken into consideration.

The observed heat stress differences in Warsaw and Tromso could affect the heat adaptation process in an organism. As a consequence, an additional adaptation load could be produced on the organism.

The energy totals (4 hours) of visible solar radiation to which selected persons (two males-P1, P3 and two females-P5, P7) were exposed during their stay in Warsaw and Tromso (on the compared days), were significantly different.

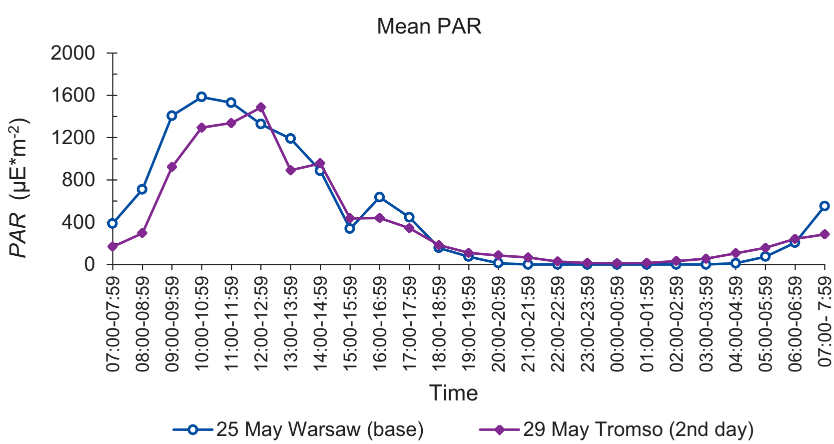

Figure 1. Daily course of photosynthetically active radiation (400-710 nm); outdoor 1- hour – means, in Warsaw (25 May) and in Tromso (29 May).

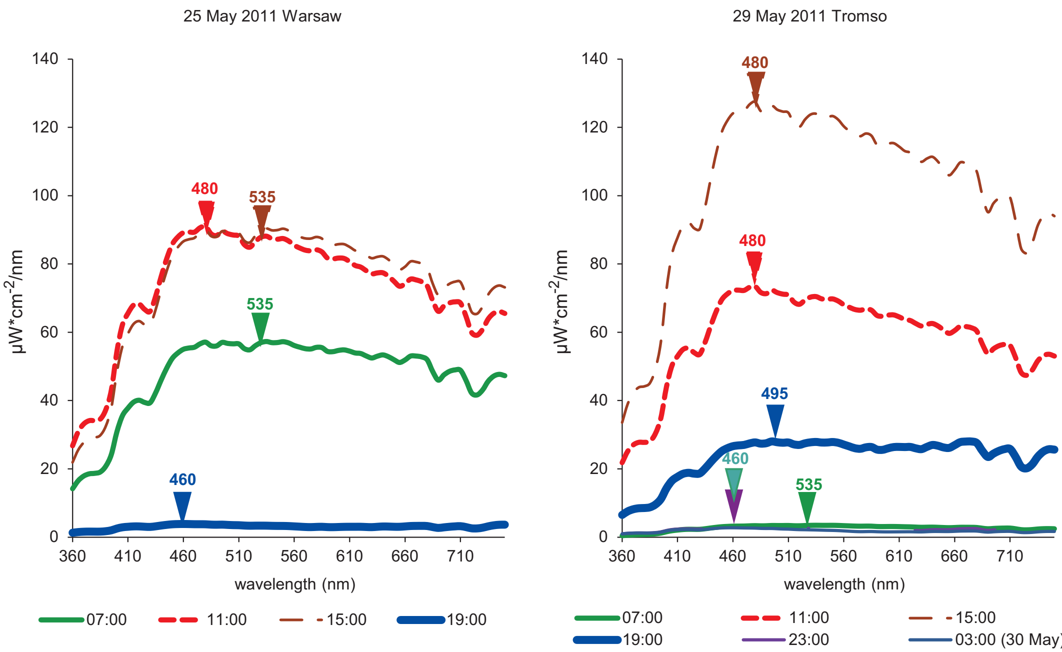

Figure 2. Irradiance (μW·cm^{-2}/nm) due to wavelengths in selected times of day: Warsaw (25 May) and Tromso (29 May).

Table 1. Meteorological parameters for selected times during the day: Warsaw (25 May) and Tromso (29 May) (based on SYNOP data).

Time UTC	Cloud cover (*N*, oktas)		Relative humidity (*RH*, %)		Temperature (°C)		Wind speed (m·s^{-1})	
	Warsaw	Tromso	Warsaw	Tromso	Warsaw	Tromso	Warsaw	Tromso
06	5/8	1/8	76	71	9	8	4.1	1.5
12	4/8	5/8	40	40	15	13	7.2	2.1
18	2/8	8/8	38	53	16	14	5.7	1.5
00	0/8	0/8	79	76	10	10	1.5	2.6

The differences are partly the result of the uneven number of hours spent outdoors on the analyzed days. Some differences in the amounts of absorbed solar radiation doses occurred even during the Tromso stay, during which subjects spent their activity time together. However, taking into account these differences the amount of energy to which volunteers (eg. P1) were exposed to in Tromso were 6 times higher during the daytime (11 am-7 pm) than in the corresponding period in Warsaw. Relatively similar amounts of radiation doses during the nighttime were noted in both locations. We expected that in Tromso during the polar day conditions this doses would be much more greater than in Warsaw. The comparable values are probably the result of light pollution in Warsaw, which is typical for urban areas.

Differentiation of illumination intensity (lux) during the analyzed periods may have caused the greatest changes in the melatonin concentration of subjects' saliva. Outdoor activities are associated with more exposure to increasing amounts of bright illumination. On sunny days, the illumination briefly measured outdoors, was usually about 10 times higher than indoors (eg. in a living room with a southern exposure – about 600 lux, while outdoors – about 6,000 lux). The daily illumination intensity in the surroundings of the selected subjects while in Tromso (outdoor activity and tourism activity prevailed) and while in their place

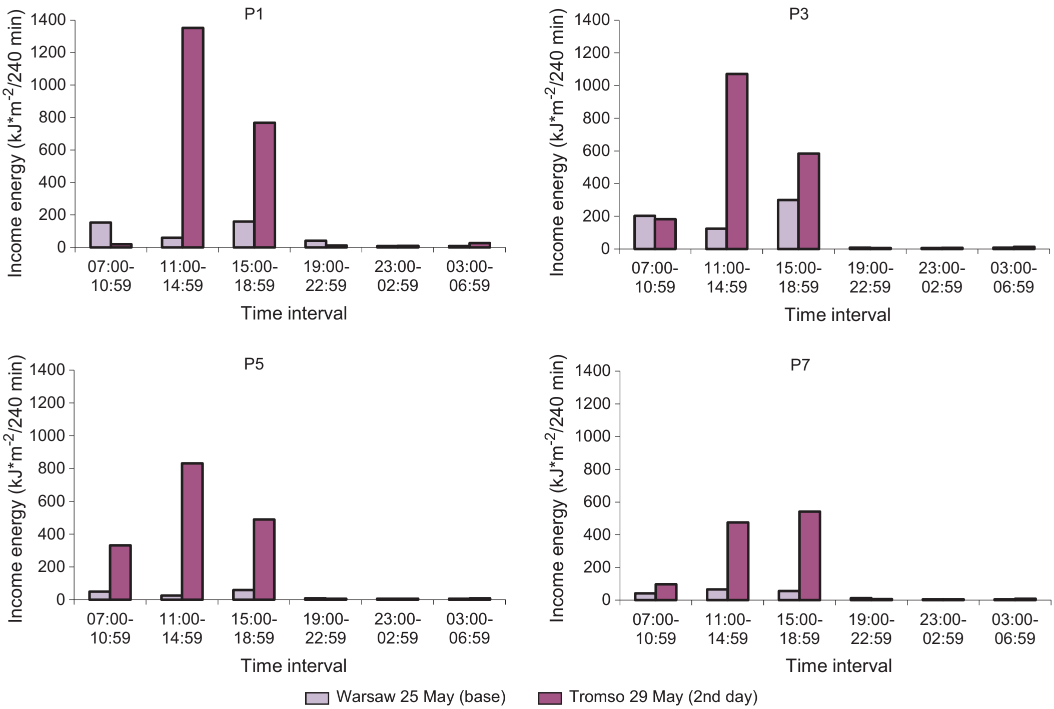

Figure 3. Visible radiation totals (240 min) for participants P1, P3 (males); P5, P7 (females) in Warsaw (25 May) and in Tromso (29 May).

of habitual residence in Warsaw is presented at Figure 4.

Base measurements of melatonin concentration in subjects' saliva, in the place of their habitual residence, were done on 25 May, on the 4th day of experiment (Fig. 5) to be used as the control measurements. Large individual differentiation was found which was similar to the findings described in literature (Arendt 2006). In the studied group of 4 males and 4 females, the level of melatonin concentration during the day (11 am-7 pm) did not exceed the value of 0.5 pg/ml. The mean concentration of MEL at eleven pm was 14.5 pg/ml (N=8, p=0.30), at three am 15.7 pg/ml (N=8, p=0.02) and at seven am 8.1 pg/ml (N=8, p=0.19). The mean Melatonin Peak on 25 May was 17.1 pg/ml and occurred at 1:53 am.

After one day of the stay in Tromso (on the second day of the stay, May, 29 2011) the concentration of MEL at 11 pm decreased (the mean for all the subjects) to 4.3 pg/ml (N=8, p=0.03). The concentration of MEL at 3 am and 7 am in most cases were higher than those observed during the control measurements, but did not differ significantly. During the daytime, from 11 am to 7 pm, the concentration of MEL did not exceed 0.5 pg/ml. The mean melatonin peak on 29 May was 16.1 pg/ml, and it occurred at 2:42 am. Individual relative changes of MEL concentration levels on 29 May (the second day of the stay in Tromso) compared to the control levels (25 May, Warsaw) are presented in Table 2.

The daily concentrations of melatonin for all subjects during the whole experiment (base day in Warsaw, 2nd, 4th and 6th day in Tromso and 2nd, 4th, 6th day after the subjects' return to Warsaw) were averaged and analysed. The results showed, as was expected, that nocturnal melatonin levels, during the period of stay in polar lighting conditions (Tromso) were lower than those observed in Warsaw on the control test day. However after returning to Warsaw, an overproduction of the hormone was noted (Fig. 6).

Discussion

Physiological studies indicate that lighting conditions throughout the day have an impact on nocturnal melatonin levels: the morning light – – affects the moment of the beginning of hormone

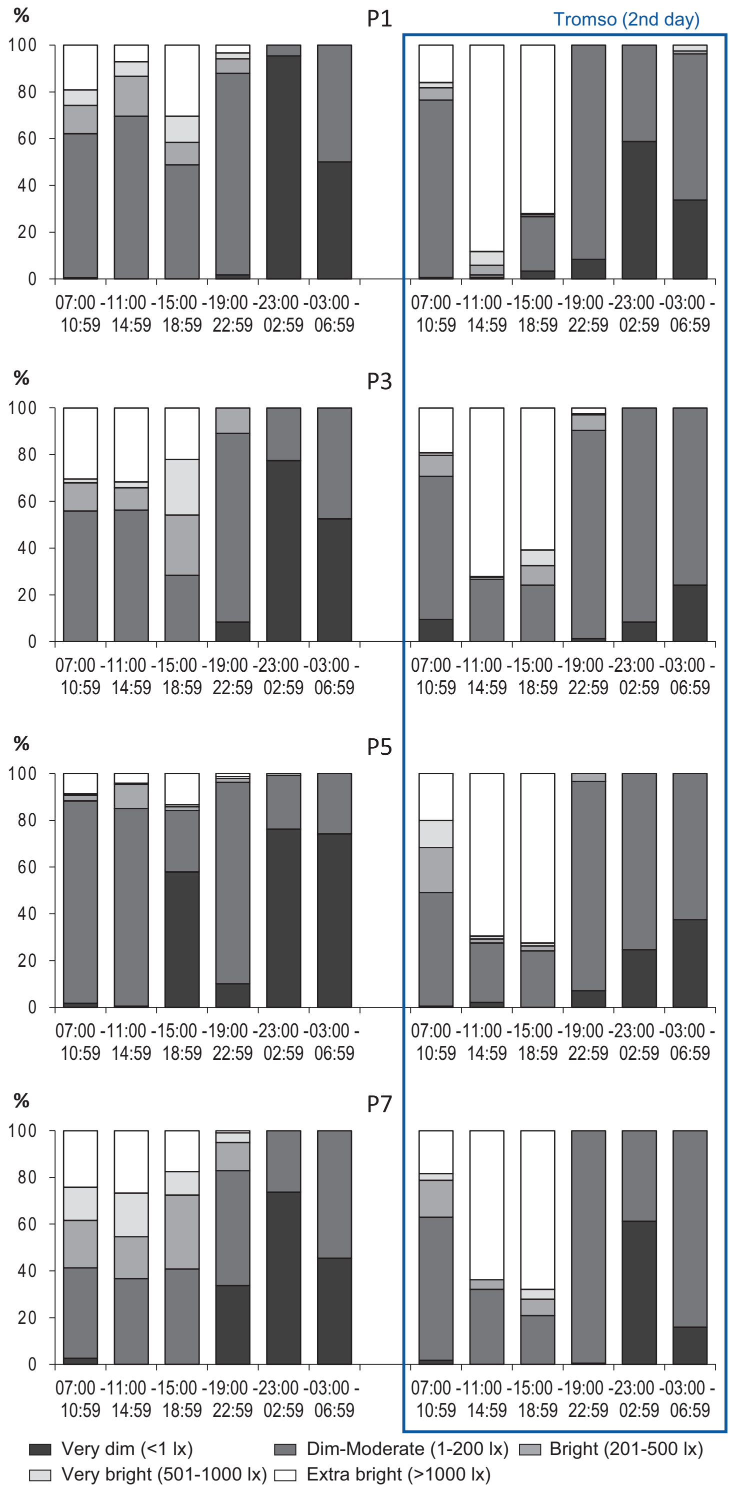

Figure 4. Frequency (%) and various intensities of light in the surroundings of participant P1, P3 (males) and P5, P7 (females) while participant were in Warsaw (25 May) and in Tromso (29 May).

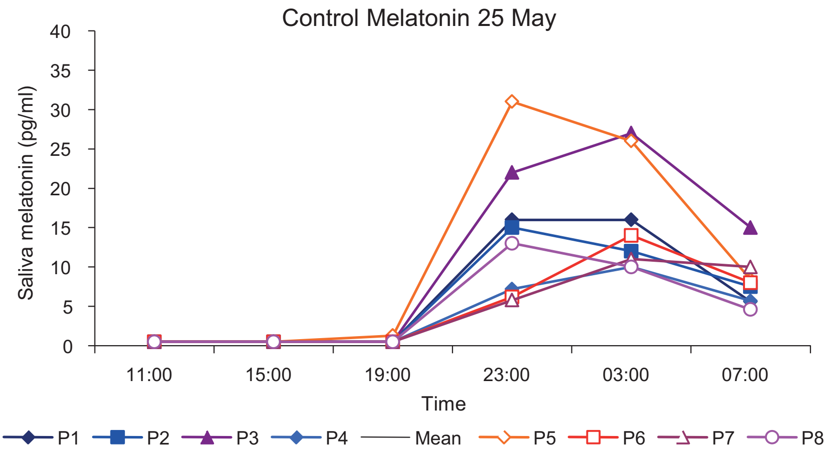

Figure 5. Diurnal course of saliva melatonin concentration (pg/ml) on May 25, 2011 (the control day). Males participant: P1-P4, females: P5-P8.

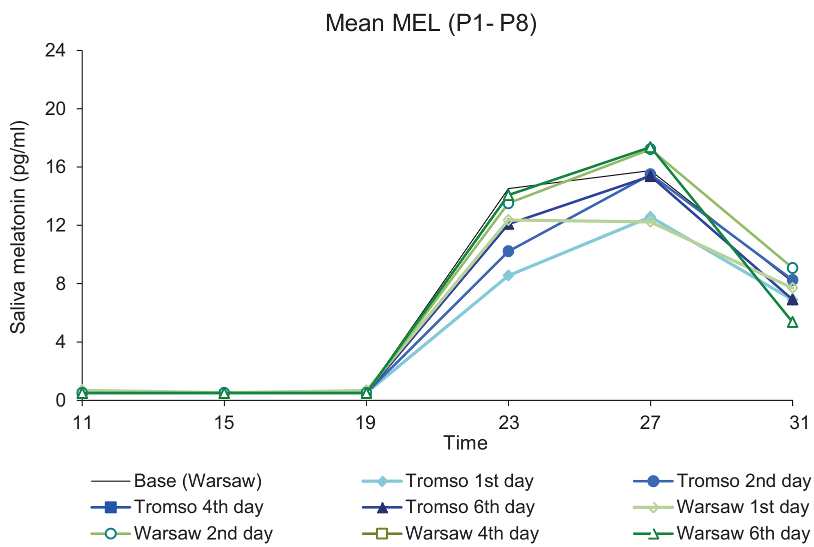

Figure 6. Mean for all participants' (P1-P8) saliva melatonin concentration (pg/ml) measured during the chosen experimental days in Warsaw and Tromso.

production, lighting during the day – affects the amplitude of the MEL cycle, while the evening light – possibly affects the melatonin phase delay and response at occurrence of darkness (Morita et al. 2002). Significant differences in the intensity of photosynthetically active radiation (PAR) observed in Tromso (compared to values noted in Warsaw can be the cause of observed changes in the melatonin production cycle after a one day stay in polar lighting conditions: changes in amplitude (1 pg/ml lower mean Melatonin Peak) and cycle shift (about a 50 minute delay of mean Time Peak).

Spectral distributions of solar radiation in both studied areas were similar. Differences in the totals of energy received by subjects, and the illumination intensity of their surrounding, were significant. The differences were partly modified by behavioral factors like activity type and time spent outdoor. The amount of radiation reaching the volunteers during the evening and during the night was obviously greater in Tromso than in Warsaw. The radiation could cause a phase delay and MEL concentration decrease, as was expected. In Tromso, the concentration of melatonin at 23 pm was, on average,

Table 2. Percentage change in melatonin concentration on the second day of the stay in Tromso compared to melatonin concentration level on 25 May (base measurement, Warsaw).

Location/ date	Warsaw-control May 25, 2011	Tromso May 29, 2011 (2nd day)		
Time (h)	23, 3, 7	23	3	7
Subject	%			
P1	100.00	-18.8	-12.5	7.1
P2	100.00	-44.7	25.0	-12.0
P3	100.00	-31.8	14.8	-13.3
P4	100.00	52.8	-40.0	15.8
P5	100.00	-38.7	-19.2	14.3
P6	100.00	-46.8	-14.3	5.0
P7	100.00	-22.4	18.2	10.0
P8	100.00	-41.5	20.0	4.3

4.3 pg/ml lower than in Warsaw. Such a concentration reflects the intensive lighting in the period before the collection of the saliva sample. The reason could be that pineal processes did not start, and thus, the observed delay in the melatonin cycle. Concentrations of melatonin at 3 am and 7 am in Tromso, were significantly higher than in the control test in Warsaw, which indicates a phase shift of the melatonin cycle. There may also be efforts by the pineal gland to compensate for previous lower concentrations of the hormone and overproduction than occurred. An additional stressing factor which can influence circadian rhythm is the active adaptation of the thermoregulatory system to changed biothermal conditions (Błażejczyk et al. 2000; Błażejczyk & Twardosz 2002). Further studies need to be conducted, especially regarding the possible influence of an organism's adaptation load to different biothermal conditions.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the author(s), on the basis of their own research.

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