The effects of gender on circadian rhythm of human physiological indexes in high temperature environment

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Abstract. In the context of frequent high temperature weather in recent years, peoples’ physical health is seriously threatened by the indoor high temperature. The physiological activities of human body show a certain changes of circadian rhythm. In this paper, the circadian rhythms of the physiological indexes in indoor high temperature environment were quantified and compared between the male subjects and female subjects. Ten subjects (five males and five females) were selected. The temperature conditions were set at 28°C, 32°C, 36°C and 38°C, respectively. The blood pressure, heart rate, rectal temperature, eardrum temperature, forehead temperature and mean skin temperature were measured for 24 hours continuously. The medians, amplitudes and acrophases of the circadian rhythms were obtained by the cosinor analysis method. Then the effects of gender on the circadian rhythm of the human body in high temperature environment were analyzed. The results indicate that, compared with the female subjects, the male medians of the systolic pressure and diastolic pressure were higher, and the male medians of heart rate and rectal temperature were lower, however, no significant differences were found between eardrum temperature, forehead temperature and mean skin temperature. This study can provide scientific basis for the health protection of the indoor relevant personnel.

1. Introduction
Circadian rhythm is the most common biological rhythm. For human body, the physiological activities show a certain changes of circadian rhythm, of which the cycle is about 24 hours [1]. In summer, the air conditioning creates comfortable environment for people to endure high temperature weather. However, some places (such as school classrooms and student dormitory) cannot afford the initial cost and operation cost of the air conditioning, and some other places (security pavilion and other remote places) are not suitable to install air conditioner, human have to stay in these places and endure the high temperature for a long time.

Many scholars conducted field measurements and environmental simulation, the results indicated that the high temperature not only seriously threatens the physical health of the human body, but also affects the social production activities and the people’s daily life [2-5]. Some studies were conducted to obtain the circadian rhythm of physiological parameters of healthy body and sick body through the experimental measurement [6-8].

Previous studies focused on the effects of environment temperature on the physiological parameters of the human body and the circadian rhythms of physiological parameters of healthy body and sick body. This paper analyzed the effects of gender on the circadian rhythms of physiological parameters. The variation characteristics of circadian rhythm under non-air-conditioning environments of the male
subjects and the female subjects were compared. This study can provide scientific basis for the
cognition of the people’s physiological response in high temperature under non-air-conditioning
environment.

2. Materials and methods

2.1. Experiment

The experiment was conducted in a top floor non-air-conditioned house in Baoding from mid-July to
mid-August in 2017. During the experiment time, natural ventilation was employed to maintain a
certain air change. The daily temperature conditions were determined according to the maximum
hourly outdoor temperature, and the temperature conditions were set at 28℃, 32℃, 36℃, 38℃ (the
maximum hourly outdoor temperature ± 1.0℃), respectively.

A total of 10 college students were selected, including 5 males and 5 females. They were aged 22.6
± 2.0 years old, their height was 167.2 ± 7.4 cm, and their weight was 61.9 ± 12.8 kg. The subjects
were required to be in good health and emotionally stable. Subjects all volunteered to participate and
got a certain reward.

During the experiment, all subjects were dressed in a short sleeve T-shirt, thin pants, underwear,
socks and slippers. On the experiment day, all subjects were requested to arrive at the experiment
house at 8:30 AM, and they rested quietly for 30 minutes to calm down their physiological and
psychological states. The experiment started from 9:00, and the physiological parameters and
environmental parameters were measured every one hour for 24 hours. The outdoor dry bulb
temperature was also measured. In the whole experiment day, the subjects were required to stay in the
experiment house, and they could rest or engage in mental activities. The experimental instruments are
shown in table 1.

| Parameter           | Instrument                   | Model             | Precision  |
|---------------------|------------------------------|-------------------|------------|
| Dry bulb temperature| Thermal index meter          | AZ8778            | ±0.6℃      |
| Heart rate          | Electronic sphygmomanometer  | OMRON HEM-7051    | ±5%        |
| Rectal temperature  | Electronic thermometer       | OMRON MC-347      | ±0.1℃      |
| Skin temperature    | Infrared temperature instrument | DT806              | ±0.3℃      |
| Forehead temperature| Infrared temperature instrument | DT806              | ±0.3℃      |
| Eardrum temperature | Infrared ear thermometer     | OMRON TH839S      | ±0.2℃      |
| Blood pressure      | Electronic sphygmomanometer  | OMRON HEM-7051    | ±4mmHg     |

The skin temperature is the weighted mean value of the chest temperature, the upper arm
temperature, the inner thigh temperature and the inner shin temperature. And the weight coefficients
are 0.3, 0.3, 0.2 and 0.2, respectively [9].

The experiment was approved by Chinese Ethics Committee of Registering Clinical Trials (No.
ChiECRCT-20170108).

2.2. Statistical method

Single cosinor analysis method was adopted to analyze the circadian rhythm of the physiological
parameters of every subject. Then based on the principle of least square, the circadian rhythm
eigenvalues (P-value, median, amplitude, acrophase) were obtained through Cosinor Periodogram
software [10]. When P was smaller than 0.05, it indicates that the variable shows circadian rhythm,
while when P is larger than 0.05, it indicates that the variable shows no circadian rhythm. The
mathematical model for the cosinor analysis method is shown in equation (1) [11]:

\[ Y_i = M + A \cos(\omega t_i + \varphi) \]  (1)
where $Y_i$ is the biological variable at time $t_i$, $M$ is the median rhythm (the mean value of rhythm adjustment), $A$ is the rhythmic amplitude (the degree of rhythm variation above or below the central line), $\omega$ is the angular frequency of rhythm (considering 24 h circadian cycle as 360°, it is 15°/h), $t_i$ represent the time of 24 hour system, $i$ can take the value 0, 1, 2, ..., 24, $\varphi$ is the acrophase of rhythm (the time interval between 0 and the time when the rhythm reaches its peak).

Through SPSS17.0 software, independent sample t test was adopted to compare the differences of the basic eigenvalues between those of male subjects and female subjects. When P is smaller than 0.05, it indicates that significant difference statistically exists.

3. Results

The single cosinor method was used to analyze the physiological indexes of males and females under the four temperature conditions. The results are shown in tables 2~8. It indicates that, both for the male group and female group, the systolic pressure, diastolic pressure, heart rate, rectal temperature, ear drum temperature, forehead temperature and mean skin temperature all had circadian rhythm (P <0.05) under the four kinds of temperature conditions.

As shown in tables 2-4, in the four temperature conditions, the medians of systolic and diastolic pressure of men were significantly higher than those of women, while the medians of male heart rate were lower (P <0.05). Moreover, the acrophases of systolic pressure and the amplitude of diastolic pressure all had no statistical difference (P> 0.05). Similar results were obtained by Xie et al. [12] and Peng et al. [13]. Compared with the results of women (3.7, 6.1 h, P <0.05), the acrophases of male diastolic pressure in the temperature conditions of 28°C and 32°C shifted back 56° and 92°, respectively, however, the acrophases of the diastolic pressure showed no statistical difference between men and women in the temperature conditions of 36°C and 38°C (P> 0.05). When the ambient temperature rose, the medians and amplitudes of systolic pressure of men and women all decreased, and the medians of diastolic pressure both decreased while the acrophases both shifted back. In addition, the medians of heart rate both increased while the acrophase of women shifted back. Gender is a common factor affecting biological rhythm. Compared with the females, the average blood pressure value of the males is higher. And majority of studies indicated that compared with men in the same age, the blood pressure of the premenopausal women is lower because of estrogen. Estrogen may not only can affect the arterial biomechanical properties by affecting vascular wall, blood pressure and lumen size, but also can improve the ability of arterial dilatation by reducing the arterial stiffness and vasodilation [14-17].

Table 2: Cosinor analysis results of the systolic pressure at the four temperature conditions (n=5).

| Groups | Gender | Median($\bar{x}$±s) | Amplitude($\bar{x}$±s) | Acrophase(°, 95%CL) | P value |
|--------|--------|------------------|------------------|------------------|---------|
| 28°C   | Male   | 118.402 ± 7.140  | 5.499 ± 0.620    | -107(-80, -134)  | 0.0240  |
| Female | 101.745 ± 4.726* | 4.706 ± 0.665    | -104(-75, -133)  | <0.0100          |
| 32°C   | Male   | 116.626 ± 7.425  | 5.559 ± 0.855    | -117(-83, -151)  | <0.0100 |
| Female | 101.487 ± 5.900* | 4.576 ± 0.347    | -108(-53, -163)  | 0.0180           |
| 36°C   | Male   | 118.261 ± 7.892  | 4.082 ± 0.860    | -115(-68, -162)  | 0.0101  |
| Female | 101.719 ± 4.753* | 3.790 ± 1.070a   | -146(-83, -208)  | 0.0332           |
| 38°C   | Male   | 114.614 ± 7.114  | 4.888 ± 0.423a   | -148(-93, -203)  | <0.0100 |
| Female | 99.582 ± 6.182Δ  | 3.647 ± 1.103Δa  | -121(-56, -187)  | 0.0210           |

Notes: *The results of the female subjects and the male subjects were compared, P<0.05 (Independent sample T test), it indicates that the difference are significant, the same below; 

Δ The results of each temperature group was compared with the group 28°C (Paired T test), P<0.05, it indicates that the difference are significant, the same below; 

Phase reference: 09:00=0°; 360°=24 hours.
Table 3. Cosinor analysis results of the diastolic pressure at the four temperature conditions (n=5).

| Groups | Gender | Median(\(\bar{x} \pm s\)) | Amplitude(\(\bar{x} \pm s\)) | Acrophase(\(^\circ\), 95%CL) | P value |
|--------|--------|-----------------------------|-----------------------------|-----------------------------|---------|
| 28°C   | Male   | 68.645 ± 8.808              | 3.415 ± 1.380               | -177(-121, -234)            | 0.0127  |
|        | Female | 62.765 ± 5.147\(^a\)       | 3.628 ± 0.758               | -121(-64, -177)\(^*\)      | 0.0220  |
| 32°C   | Male   | 67.614 ± 9.735\(^a\)       | 3.719 ± 1.064               | -210(-158, -261)            | 0.0170  |
|        | Female | 61.970 ± 5.063\(^a\)       | 3.174 ± 0.806               | -118(-66, -170)\(^*\)      | 0.0141  |
| 36°C   | Male   | 68.012 ± 9.507              | 4.200 ± 1.262               | -189(-140, -238)            | 0.0131  |
|        | Female | 61.723 ± 3.300\(^a\)       | 3.684 ± 0.765               | -198(-145, -251)            | <0.0100 |
| 38°C   | Male   | 66.199 ± 8.130\(^a\)       | 5.001 ± 0.890               | -277(-219, -334)\(^a\)     | <0.0100 |
|        | Female | 61.300 ± 4.740\(^a\)       | 3.677 ± 1.700               | -213(-140, -285)\(^a\)     | 0.0174  |

Table 4. Cosinor analysis results of the heart rate at the four temperature conditions (n=5).

| Groups | Gender | Median(\(\bar{x} \pm s\)) | Amplitude(\(\bar{x} \pm s\)) | Acrophase(\(^\circ\), 95%CL) | P value |
|--------|--------|-----------------------------|-----------------------------|-----------------------------|---------|
| 28°C   | Male   | 76.143 ± 7.880              | 5.807 ± 2.755               | -86(-37, -136)              | <0.0100 |
|        | Female | 79.738 ± 6.371\(^*\)       | 4.474 ± 0.776               | -62(-17, -108)              | 0.0151  |
| 32°C   | Male   | 77.176 ± 8.016              | 5.159 ± 1.944               | -110(-76, -144)             | 0.0216/ |
|        | Female | 81.437 ± 7.478\(^a\)       | 4.875 ± 2.011               | -136(-80, -192)\(^a\)      | 0.0220  |
| 36°C   | Male   | 80.950 ± 10.254\(^a\)      | 7.570 ± 2.960               | -98(-53, -142)              | <0.0100 |
|        | Female | 82.113 ± 8.600\(^a\)       | 7.960 ± 0.780               | -56(-49, -63)               | <0.0100 |
| 38°C   | Male   | 81.080 ± 13.12\(^a\)       | 6.016 ± 3.054               | -108(-56, -161)             | 0.0148  |
|        | Female | 83.534 ± 7.037\(^a\)       | 4.8035 ± 1.07               | -111(-91, -130)\(^a\)      | 0.0290  |

Table 5. Cosinor analysis results of the rectal temperature at the four temperature conditions (n=5).

| Groups | Gender | Median(\(\bar{x} \pm s\)) | Amplitude(\(\bar{x} \pm s\)) | Acrophase(\(^\circ\), 95%CL) | P value |
|--------|--------|-----------------------------|-----------------------------|-----------------------------|---------|
| 28°C   | Male   | 36.709 ± 0.164              | 0.330 ± 0.163               | -114(-74, -153)             | <0.0100 |
|        | Female | 36.841 ± 0.084\(^*\)       | 0.146 ± 0.020\(^*\)        | -96(-60, -131)              | <0.0100 |
| 32°C   | Male   | 36.764 ± 0.137              | 0.299 ± 0.039               | -119(-96, -142)             | <0.0100 |
|        | Female | 36.954 ± 0.111\(^a\)       | 0.181 ± 0.025\(^a\)        | -121(-56, -187)             | <0.0100 |
| 36°C   | Male   | 36.936 ± 0.274\(^a\)       | 0.452 ± 0.143               | -107(-72, -141)             | <0.0100 |
|        | Female | 37.093 ± 0.073\(^a\)       | 0.411 ± 0.146\(^a\)        | -91(-81, -102)              | <0.0100 |
| 38°C   | Male   | 37.055 ± 0.176\(^a\)       | 0.473 ± 0.069               | -131(-89, -172)             | <0.0100 |
|        | Female | 37.148 ± 0.077\(^a\)       | 0.369 ± 0.165\(^a\)        | -128(-115, -143)            | <0.0100 |

As shown in Table 5, the medians of rectal temperature of the male subjects were lower than those of the female subjects in the four temperature conditions (P <0.05), while the acrophases of the rectal temperature had no statistical difference (P> 0.05) and the amplitudes of rectal temperature of the male subjects at group 28°C and group 32°C were all higher than those of the female subjects (P <0.05). The experimental data was similar to that of Jiang and Wang [18]. And compared with the results of group 28°C, the medians of the male and female subjects and the amplitudes of the female subjects were all significantly higher. The body temperature of the males is usually lower than that of the females, and this difference exists at birth [19]. Because the fetus in the uterus needs constant temperature environment, as a result, the ‘sensor’ in female skin is more sensitive. Furthermore, progesterone secreted by the female ovarian corpus luteum would cause the rise of body temperature, and a certain amount of progesterone (12.8 nmol/L) could cause the increase of body temperature. In
addition, the amount of fat in women body (higher than that of men) also leads to the increase of body temperature.

Table 6. Cosinor analysis results of eardrum temperature at the four temperature conditions (n=5).

| Groups | Gender | Median(±sx) | Amplitude(±sx) | Acrophase (°, 95%CL) | P value |
|--------|--------|-------------|----------------|-----------------------|---------|
| 28℃    | Male   | 35.604±0.177 | 0.458±0.114 | -110(-90, -129) | <0.0100 |
|        | Female | 35.682±0.215 | 0.359±0.108 | -88(-40, -136) | <0.0100 |
| 32℃    | Male   | 35.664±0.153 | 0.369±0.126 | -138(-113, -163) | <0.0100 |
|        | Female | 35.762±0.182a | 0.421±0.094 | -111(-86, -137) | <0.0100 |
| 36℃    | Male   | 36.299±0.040a | 0.677±0.060 | -115(-102, -127) | <0.0100 |
|        | Female | 36.265±0.116a | 0.509±0.110 | -111(-102, -120) | <0.0100 |
| 38℃    | Male   | 36.376±0.160a | 0.499±0.250 | -121(-94, -147) | <0.0100 |
|        | Female | 36.310±0.166a | 0.429±0.200 | -126(-115, -137) | <0.0100 |

Table 7. Cosinor analysis results of the forehead temperature at the four temperature conditions (n=5).

| Groups | Gender | Median(±sx) | Amplitude(±sx) | Acrophase (°, 95%CL) | P value |
|--------|--------|-------------|----------------|-----------------------|---------|
| 28℃    | Male   | 36.647±0.072 | 0.126±0.033 | -101(-66, -136) | 0.0110  |
|        | Female | 36.623±0.250 | 0.111±0.036 | -101(-49, -152) | <0.0100 |
| 32℃    | Male   | 36.665±0.077 | 0.149±0.019 | -120(-99, -140) | <0.0100 |
|        | Female | 36.677±0.296a | 0.138±0.036 | -103(-62, -143) | <0.0100 |
| 36℃    | Male   | 36.701±0.096a | 0.170±0.069 | -92(-43, -143) | 0.0140  |
|        | Female | 36.778±0.260a | 0.202±0.131 | -99(-64, -135) | <0.0100 |
| 38℃    | Male   | 36.795±0.148a | 0.236±0.141a | -131(-69, -193) | <0.0100 |
|        | Female | 36.828±0.228a | 0.208±0.033a | -117(-52, -182) | <0.0100 |

Table 8. Cosinor analysis results of the mean skin temperature at the four temperature conditions (n=5).

| Groups | Gender | Median(±sx) | Amplitude(±sx) | Acrophase (°, 95%CL) | P value |
|--------|--------|-------------|----------------|-----------------------|---------|
| 28℃    | Male   | 36.139±0.092 | 0.176±0.075 | -102(-63, -140) | <0.0100 |
|        | Female | 36.155±0.221 | 0.206±0.133 | -140(-115, -164) | <0.0100 |
| 32℃    | Male   | 36.168±0.120 | 0.209±0.040 | -142(-92, -193) | <0.0100 |
|        | Female | 36.166±0.243 | 0.220±0.104 | -127(-80, -175) | <0.0100 |
| 36℃    | Male   | 36.292±0.148a | 0.179±0.050 | -121(-69, -173) | <0.0100 |
|        | Female | 36.316±0.183a | 0.229±0.083 | -128(-84, -173) | <0.0100 |
| 38℃    | Male   | 36.340±0.148a | 0.216±0.078 | -105(-86, -124) | <0.0100 |
|        | Female | 36.383±0.174a | 0.162±0.063 | -96(-52, -140)a | <0.0100 |

As shown in tables 6-8, in the four temperature conditions, compared with the relevant results of the female subjects, there were no significant differences in the median and amplitude of eardrum temperature, forehead temperature and mean skin temperature (P> 0.05). And the medians of all male and female subjects of group 36℃ and group 38℃ were all higher than those of group 28℃ (P <0.05).

4. Conclusions
In this paper, the circadian rhythms of the physiological indexes in indoor high temperature environment were quantified and compared between the male subjects and female subjects. The temperature conditions were set at 28℃, 32℃, 36℃ and 38℃, respectively. The physiological
indexes of the subjects in non-air-conditioning rooms as well as outdoor temperatures were measured every hour for 24 hours. The medians, amplitudes and acrophases of the circadian rhythms were obtained by the cosinor analysis method. Then the effects of gender on the circadian rhythm of the human body in high temperature environment were analyzed. The main conclusions of this paper include:

1) The systolic pressure, diastolic pressure, heart rate, rectal temperature, forehead temperature, eardrum temperature, and mean skin temperature of both male subjects and female subjects in the four temperature conditions all show circadian rhythm.

2) For systolic pressure, the medians of the male subjects were lower than those of the female subjects. While for heart rate, the medians of the female subjects were higher than those of the male subjects.

3) For rectal temperature, the medians of the female subjects were higher than those of the male subjects. While for eardrum temperature, forehead temperature and mean skin temperature, the differences of circadian rhythms between male subjects and female subjects were not obvious.

This study is beneficial to seek the physiological commonness of some related people in hot weather, then it can provide scientific basis for the cognition of the people’s physiological response in high temperature under non-air-conditioned environment.

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