Experimental study on the effect of various exercise intensities and thermal environments on thermal responses

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Abstract[1]:

Public exercise facilities have recently emerged across China. This study aims to investigate the impacts of exercise intensity and thermal environment on thermal responses as well as examine the dynamic changes and differences in thermal responses during exercise. Using a controlled thermal chamber, university students were assessed at varying walking speeds under six thermal conditions, from -15 to 35°C. Their psychological and physiological responses were observed and recorded in real time during the thermal adaption, exercise, and rest phase. Firstly, the exercise intensity significantly affected heart rate and metabolic rate, whereas the thermal environment had no significant effect. The effect of the thermal environment on skin temperature, thermal sensation vote (TSV), and thermal comfort vote (TCV) was more pronounced than that of exercise intensity. Secondly, during exercise, the metabolic rate took 6-9 minutes to stabilise, and the psychological response lagged compared to the physiological response. Thermal sensation was closest to neutral at 15°C, 5°C, and -5°C when walking at 3 km/h, 4.50 km/h, and 6 km/h, respectively. Thermal comfort vote (TCV) levels were greater for higher exercise intensities at -15 to 5°C, lower for higher exercise intensities at 25 to 35°C, and similar for varied exercise intensities at 15°C. Finally, current thermal comfort guidelines underestimate the exercise metabolic rate by at least 9.7%. This study helps clarify the dynamic changes and influences of thermal responses during exercise and provides a reference for future research on exercisers' thermal responses.

Keywords:

Thermal response, Exercise intensity, Thermal environment, Dynamic walking process, Metabolic rate

Nomenclature

HR: heart rate, bpm

MR: metabolic rate, met

PMV: Predicted Mean Vote

Tskin: skin temperature, °C

TSV: Thermal sensation vote

TCV: Thermal comfort vote

Top: Operative temperature, °C

UTCI: Universal Thermal Climate Index, °C

1. Introduction

A thermally controlled indoor space provides a stable and comfortable environment to exercisers. However, prolonged exercise in an artificial environment can weaken one's resistance to environmental changes and cause air conditioning disease, which contradicts the original intention of maintaining health through exercise [1-3]. To support the pursuit of a healthy life, exercise facilities like sports theme parks and urban activity plazas have become widespread in recent years, and research on thermal response for exercisers has gained momentum.

Thermal response is the result of the combined responses of physiology and psychology; the former includes skin temperature (Tskin), heart rate (HR), metabolic rate (MR), etc., while the latter includes thermal comfort vote (TCV), thermal sensation vote (TSV), thermal acceptance voting, etc [4-7]. Previous studies have evaluated the effects of several factors on the thermal perception of exercisers, such as exercise intensity, type of exercise, thermal environmental parameters, gender, and activity spaces [8-12]. Most of these studies were conducted under low to medium levels of activity intensity and used climate chambers to better control the stability of environmental parameters.

In terms of physiological response, Choi [13], through environmental chamber experiments, found that individual differences in HR were large at higher exercise intensities. Ji et al. [14] suggested that the human body took 5-6 min to reach a new metabolic level after bicycle riding and 7-9 min to return to a sedentary MR after stopping an exercise. Zhang et al. [15] noted that the time for MR to stabilise was 3-5 min after starting walking. Bulcao et al. [16] concluded that TCVs were influenced by a combination of Tskin, HR, and other physiological responses and were closely related to the body's core heat production during exercise. Kenshalo et al. [17] found that Tskin was insensitive to a slow rate of environmental temperature change and that thermal comfort was impacted by Tskin to the degree that the speed of temperature change was linked. Yao et al. [18] found that Tskin affected thermal comfort and that higher rates of temperature change had a significant effect on thermal sensation. Zhai et al. [9] discovered that mean Tskin was identical under the same temperature circumstances when the MR was 2 to 4 met showing a minimal influence of MR on mean Tskin in this range.

In terms of psychological response, Li et al. [19] evaluated the recovery time of psychological indicators of exercise at different intensities in summer and provided temperature intervals for thermal acceptance. Wang et al. [20] found a significant effect of exercise intensity on TSV and TCV through experiments in the environmental chamber, and the physiological response had an effect on the psychological response. McNall et al. [21] conducted experimental studies and found that exercise intensity affected TSV; the higher the exercise intensity, the lower the neutral temperature. Nielsen et al. [22] found that human exercise affects the preferred temperature for TCV. Fujimoto et al. [23] found that exercise significantly enhanced overall thermal sensation compared to a sedentary state, while the effect on local skin thermal sensation was insignificant. Zhai et al. [9,24] found that the TCV of exercises performed in a high temperature and wind speed environment was even higher than that of a sedentary state in a low-temperature environment.

Additionally, many scholars found that the MR values in the current ISO and ASHRAE standards differed from the actual measured values. Zhai et al. [25] found that the MR for walking speed of 3 km/h and 6 km/h were 2.5 met and 4.9 met, respectively, and concluded that the current standards underestimated the actual MR, which would cause a large bias in comfort temperature. This view is corroborated by studies conducted by Nomoto et al [26-28]. This indicates that the reference values provided by the existing standards differ significantly from some of the actual MR during exercise, and the prediction of thermal response using these data as reference has some potential inaccuracy.

There are several differences and innovations between this study and previous ones. First, this study focuses on the outdoor environment in areas with large annual temperature differences, using six ambient temperatures as the thermal environment background: -15, -5, 5, 15, 25, and 35°C. Using an environmental chamber as the experimental site to create a relatively stable thermal environment allows us to explore a broader temperature threshold. Second, walking is a highly popular outdoor exercise, and the participants of this study adopt various walking speeds, including strolling, walking, and jogging, with medium to high exercise intensity rather than resting or low-intensity exercise. Third, the exerciser's thermal response involves subjective psychological response and thermal physiological response, and data on thermal response are assessed during the exercise process rather than solely post-exercise. The study results can be used to design a comfortable and healthy thermal environment for exercise spaces and improve the exercise performance and participation level in areas with large annual temperature differences. The main objectives of this study are as follows: (1) to identify the role of the exercise intensity and thermal environment on thermal response during exercise; (2) to compare the differences in thermal response between various exercise intensity and thermal environment during exercise; and (3) to compare the differences between actual measured values of MR and current standards.

2. Methods

2.1 Location and subjects

This study was conducted in Harbin, Heilongjiang Province, China, which belongs to the Hot Summer Continental (Dwa) according to the Koppen climate classification, with an annual temperature difference of up to 40°C. The respondents comprised college students living in Harbin for more than one year. Taking into account the statistical power level, effect size (effect size = 0.25, $\alpha = 0.05$, $1-\beta = 0.96$), and experimental conditions, a total of 144 healthy college students voluntarily participated in the experiment, of which 48.3% were female and 51.7% were male. The protocols were approved by the university’s ethics committee. Subjects were enrolled in all experimental sessions, and they were asked to refrain from smoking, drinking alcohol or coffee, and performing strenuous exercise 24 h before the experiments. Table 1 summarizes the general information of the subjects.

Table 1

Subject anthropometric data (mean value ± standard deviation).

Gender	Age(year)	Height(m)	Weight(kg)	BMI (kg/m^2)	BMR (kcal/day)	ADu
Males	24.7±1.3	1.76±0.04	72.1±9.4	22.4±1.9	1700.6±137.2	1.87±0.12
Females	26.0±3.2	1.66±0.05	56.6±9.1	20.5±1.8	1329.1±139.6	1.61±0.13
Total	25.3	1.71	65.0	22.1	1530.3	1.75

BMI is body mass index (kg/m2); BMR is basal metabolic rate (kcal/day); A_{Du} is surface area of body (m^2)

2.2 Facilities and measurements

2.2.1 Thermal environment measurements

A climate chamber was used for the experimental study. It is combined with a cold and hot chamber (Fig. 1-a, http://www.syzwh.com/Z_Product/ProductInfo?Id=2580), which simulates the outdoor climate environment by controlling the environment parameters (including temperature, humidity, wind speed, etc.). Considering the performance of the experimental equipment and the characteristics of the local outdoor climate [30], six sets of thermal environment conditions were set up in this study, and the environmental parameters were controlled to be constant during the experiment. Microclimate recorders were placed in the climate chamber to monitor and record the thermal environmental data. Considering that the activity type was walking, the instruments were fixed at a height of 1.7 m above the ground [31]. The parameters of instruments are shown in Table 2, and the instruments were calibrated according to relevant standards and guidelines [4, 61, 62]. The measured environmental parameters in the thermal chamber are shown in Table 3.

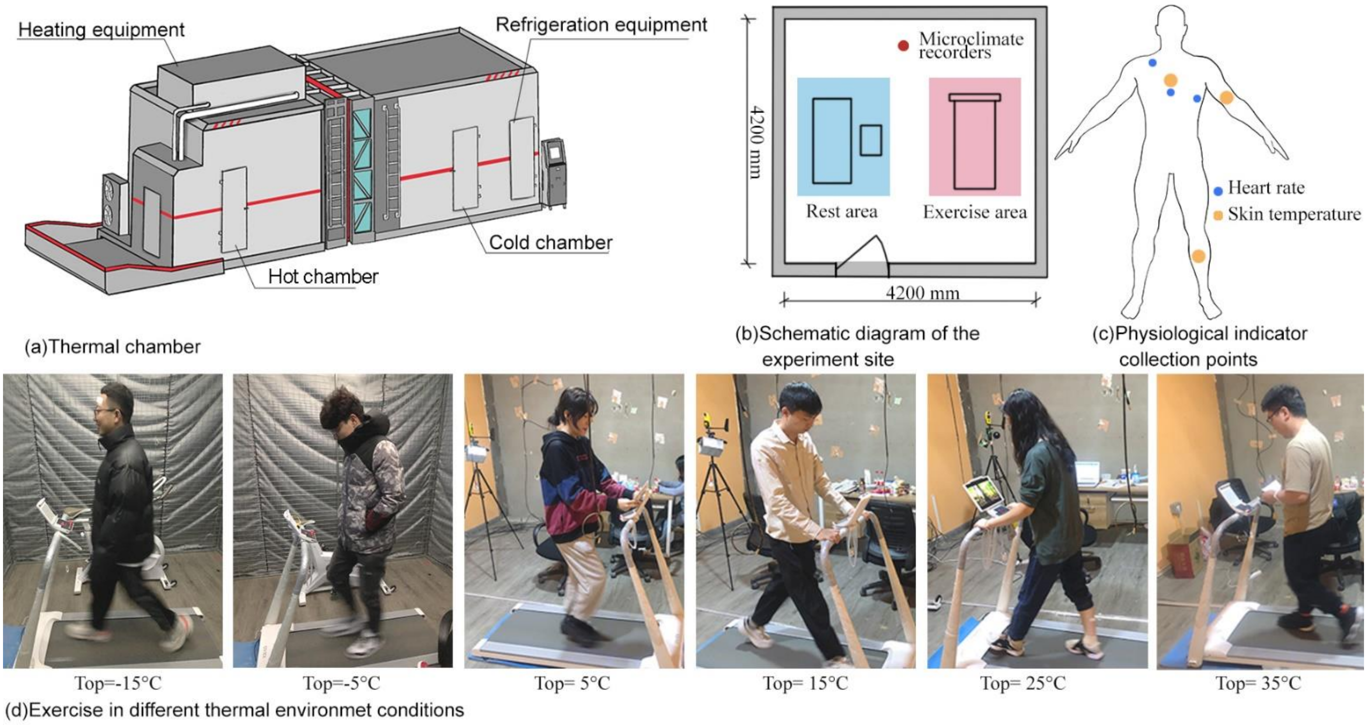

Fig 1. Information about the experiment site and photos of the experiment process

Table 2

Technical parameters of the instruments

	Type	Parameter	Range	Accuracy	Sampling rate
	BES-02	Air temperature, relative humidity	-30~50℃, 0~99.0%	≤0.5℃, ≤3.0%	1min
	Kestrel 5500	Wind speed	0.1~40.0 m/s	0.1 m/s	1min
	iButton DS1922L	Skin temperature	-40~ 85℃	±0.5℃	1min
	Careshine CCS-103	Heart rate	30~ 200bmp	±5% or ±5bmp	1min

Table 3

Environmental parameters in the controllable thermal chamber.

	Operative temperature (℃)	Measured air temperature (℃)	Measured wind speed (m/s)	Measured relative humidity (%)	Illumination (Lux)
Set 1	-15	-15.1 ±0.2	0.5 ±0.1	63 ±3.2	300
Set 2	-5	-5.4 ±0.3	0.5 ±0.2	62 ±3.4	300
Set 3	5	4.9 ±0.2	0.5 ±0.1	58 ±5.3	300
Set 4	15	15.3 ±0.5	0.5 ±0.2	48 ±3.6	300
Set 5	25	27.4 ±0.3	0.5 ±0.2	51 ±3.1	300
Set 6	35	34.8 ±0.5	0.5 ±0.1	58 ±4.7	300

2.2.2 Physiological measurements

Data regarding physiological response were collected by portable devices. A Careshine Electronic heart rate monitor (CCS-103, Careshine Electronic Technology Ltd, Table 2) [32], which was stored in the subjects' pocket and linked to the electrode pads via skin-friendly wires, recorded the heart rate during the experiment. The electrode pads were placed on three points of human body, as shown in Fig. 1(c).

The metabolic rate is usually calculated via the measurement of the ventilation [14] or heart rate [15]. For the former method, most current instruments require individuals to remain at rest and wear uncomfortable masks [36,37]. This makes it unsuitable for the measurement of motion activities and for field studies [38]. The latter is more suitable for respondents who are exercising. Therefore, we used the heart rate method to calculate the metabolic rate as in equation (1) [33, 34].

$$MR = \frac{(MWC - M_0)}{(HR_{max} - HR_0)} \times (HR - HR_0) + M_0 \qquad (1)$$

where

MR is the metabolic rate, in W/m^2 or met, 1met= 58.15 W/m^2;

MWC is the maximum work capacity, in W/m^2;

M_0 is the resting metabolic rate, in W/m^2;

HR_{max} is the maximum heart rate, in beats per minute (bpm);

HR_0 is the heart rate at rest, in bpm. HR_0 is the lowest point of heart rate recorded during the observed period (at complete rest, e.g., upon waking up);

HR is the heart rate at the moment, in bpm.

The maximum working capacity MWC (W/m2) is estimated using Eqs. (1-1) and (1-2) as a function of age (A, in years) and weight (W, in kg) for men and women [35]:

$$\text{Men:} MWC = (41.7 - 0.22A) \times W^{0.666} \quad (1\text{-}1)$$

$$\text{Women: } MWC = (35.0 - 0.22A) \times W^{0.666} \quad (1\text{-}2)$$

M_0 is calculated by Eqs. (1-3) and (1-4) for men ($M_{0,m}$) and women ($M_{0,w}$), where H (cm)is the height of the subject [36, 37].

$$Men: M_{0,m} = 0.2 + 0.484 \times W + 0.303 \times H - 0.238 \times A \quad (1\text{-}3)$$

$$Women: M_{0,w} = M_{0,m} - 8 \quad (1\text{-}4)$$

HR_{max} is calculated from Eq. (1-5) [35].

$$HR_{max} = 205 - 0.62 \times A \quad (1\text{-}5)$$

Skin temperature was recorded by iButtons DS1922L (Table 2). To reduce the discomfort caused by the instruments attached to the body surface during exercise, the Burton three-point method was used to calculate the mean skin temperature by equation (2) [38, 39, 40]. Three iButtons were attached to the subject's chest, upper arm, and lower leg by steam permeable surgical tape to ensure close contact with the subject's skin (Fig. 1-c).

$$T_{skin} = 0.5 \times T_{chest} + 0.14 \times T_{upperarm} + 0.36 \times T_{lowerlimb} \quad (2)$$

Where T_{skin} is the mean skin temperature (°C), T_{chest} is the skin temperature of the chest (°C), $T_{upperarm}$ is the skin temperature of the upper arm (°C), and $T_{lowerlimb}$ is the skin temperature of the lower limb (°C).

2.2.3 Questionnaire survey

The questionnaire comprised questions on basic information about the respondents, and the thermal sensation and comfort vote (Appendix, Fig. A. 1). Basic information about the respondent included gender, age, height, weight, and clothing. The TSV was evaluated on a seven-point scale: − 3: cold, − 2: cool, − 1: slightly cool, 0: neutral, 1: slightly warm, 2: warm, and 3: hot. The TCV was evaluated on a five-point scale: − 2: very uncomfortable, − 1: uncomfortable, 0: neutral, 1: comfortable, and 2: very comfortable [4, 41, 42]. The overall clothing thermal resistance (I_{cl}) was estimated using the empirical formula recommended by ISO 9920 as given in equation (3), and the thermal insulation values for individual garments were filtered from the of Annex B, ISO 9920 [29]. Therefore, the mean values of the thermal resistance of the clothing of the subjects at the -15, -5, 5, 15, 25 and 35°C were 1.6, 1.5, 1.3, 1.0, 0.7, and 0.5 clo, respectively (Fig. 1-d), which is consistent with the observed levels of thermal resistance of Harbin outdoor clothing in the respective thermal environment [30].

$$I_{cl} = 0.161 + 0.835 \sum I_{clu} \qquad (3)$$

2.3 Experimental protocol

The climate chamber features an exercise and a rest area. The exercise area is equipped with a treadmill with the speed range of 0 to 12 km/h and the adjustment accuracy of 0.1 km/h. The rest area is equipped with a chair and a desk. During the exercise phase, respondents walk at a set speed on a flat treadmill, while during the rest phase they keep sedentary on the chair (Fig. 1-b). An assistant was available throughout the experiment to help the participants put on and set up the instruments, introduce the experiment procedure, adjust the speed of the treadmill, and to ensure their safety. As shown in Fig. 2, respondents were required to arrive at least 15 min before the test. During the preparation phase, basic information about the participants was recorded and the participants were fitted with a skin temperature and heart rate detector. In previous studies where the intensity of exercise was close to that of this study, the exercise duration of the experiment was designed to range from 8 to 20 min [14, 15]. Furthermore, considering that a long experiment can cause fatigue that may lead to negative emotions that affect the psychological responses [40, 70], the exercise duration and rest period were set at 12 min in this study. During the thermal adaptation phase, the participant sat in the climate chamber for 24 min. Three sets of walking exercises (each including an exercise and a rest phase) were performed in sequence: Exercise 1 (3km/h), Rest 1, Exercise 2 (4.5km/h), Rest 2, Exercise 3 (6km/h) and Rest 3. The questionnaire survey was filled every three minutes and the physiological responses were recorded every one minute from the thermal adaptation phase until the end of the experiment.

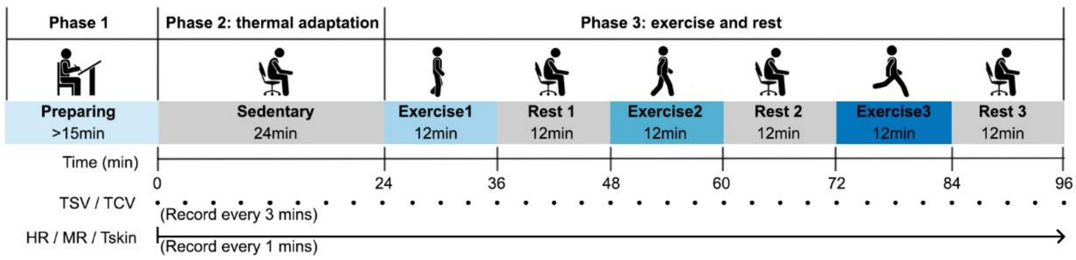

Fig 2. The experimental procedure.

2.4 Data processing

There were six sets of thermal environment conditions, each of which 24 subjects were invited, for a total of 144 subjects that participated in this experiment. The differences in physiological and psychological responses to different thermal conditions and exercises were analysed for significance by one-way ANOVA and repeated-measures ANOVA tests, respectively, and the differences were considered significant at the 0.05 level. Excel was used for data counting, categorization, and pre-processing, and all statistical analyses were done using SPSS V22.0 (IBM) and Origin 2021 (Origin Lab).

3. Results

3.1 Influencing factors and differences in physiological responses

3.1.1 Heart rate and metabolic rate

The magnitude of HR variation (difference between maximum and minimum values) in healthy people performing low to moderate intensity exercise does not exceed 100 bpm [43]. In this study, the respondents' HR variation ranged from 39 to 89 bpm; therefore, the measured data were within an acceptable range. A three-way repeated-measures ANOVA was performed on the HR and MR. As shown in Table 4, exercise intensity and duration significantly affected HR and MR during the exercise phase (0-12 min), while no significant difference on thermal environment was observed. Therefore, the HR and MR were averaged separately for different thermal environments to analyse their dynamic characteristics, as shown in Fig. 3. HR and MR follow a similar dynamic trend during exercise, i.e., a rapid increase at the beginning of the exercise, a slow and steady increase during subsequent exercise duration, a rapid decrease after cessation of exercise, and a gradual return to sedentary levels. Post hoc tests were performed at each level of exercise intensity to obtain the time taken for stabilisation of the HR and MR at the three exercise intensities. The difference in HR and MR between 6 and 12 min was not significant (p>0.05) for exercises 1 and 2, and between 9 and 12 min for exercise 3 (p>0.05). Thus, the time taken for HR and MR to reach a new steady state for exercises 1 and 2 is 6 min, while it stands at 9 mins for exercise 3. The higher the intensity of exercise, the higher the HR and MR after stabilisation, with HRs of 99±6 bpm, 114±6 bpm, and 130±8 bpm for exercise 1, 2, and 3, respectively, and MR of 2.7±0.39 met, 3.4±0.47 met, and 4.5±0.81 met, respectively. As observed by Zhai et al. [25] regarding the standard deviation, individual variability between HR and MR differed between exercises, with individual differences becoming greater with increasing exercise intensity.

Table 4

Significance of the effects of exercise intensity, thermal environment, and exercise duration on heart rate and metabolic rate

	Thermal environment					Exercise intensity					Exercise duration				
	df		F	Sig.	η^2	df		F	Sig.	η^2	df		F	Sig.	η^2
HR	5	414	1.59	0.071	0.01	2	414	40.49	0.000	0.35	1.93	295.70	40.80	0.000	0.21
M	5	414	0.95	0.452	0.03	2	414	34.34	0.000	0.31	1.84	281.84	55.2	0.000	0.27

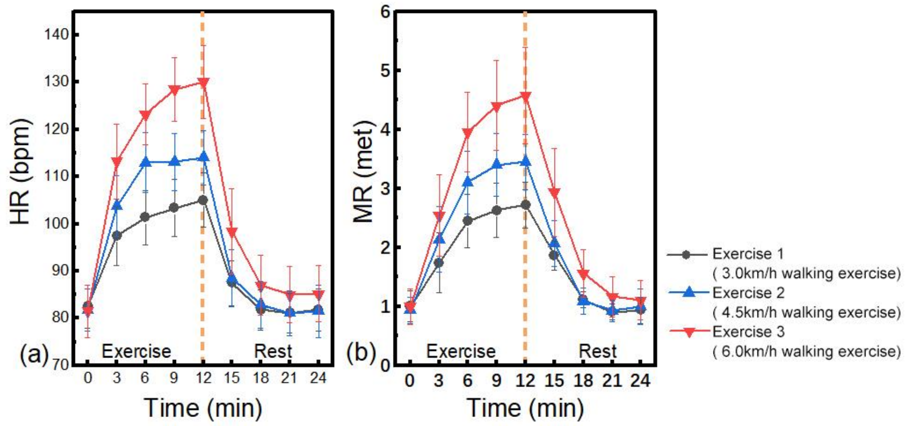

Fig 3. Measured mean value and standard deviation (SD) of the heart rate (HR) (a), and metabolic rate (MR) (b)

One-way repeated-measures ANOVA was performed to the last record of HR at sedentary phase, exercise 1, rest 1, exercise 2, rest 2, exercise 3, and rest 3 to determine whether the HR at each phase was significantly different, as shown in Fig. 4(a). The results indicated that a change in physical activities significantly affected HR [Greenhouse-Geisser adjusted F (3.16,176.85) =188.05, p<0.001], and pair-wise comparisons showed that HR at the end of rest 1 (82±9), rest

2 (81±11), and rest 3 (85±12) were all non-significantly different (p=1.000) from that observed in the sedentary phase (83±9). Similarly, the ANOVA results for MR are shown in Fig. 4(b). The results showed a significant effect on MR in each stage [Greenhouse-Geisser adjusted F (2.29,128.22) =176.37, p<0.001], and pair-wise comparisons showed that the MRs of the sedentary phase (1.0 ± 0.3) were not significantly different from those obtained during rest 1 (0.9 ± 0.4), rest 2 (1.0 ± 0.6), and rest 3 (1.1 ± 0.7). Therefore, the experimental design of increasing exercise intensity and resting for 12 min between exercise phases ensures that HR and MR have been reduced sufficiently, so as to not affect the results of subsequent exercise phases.

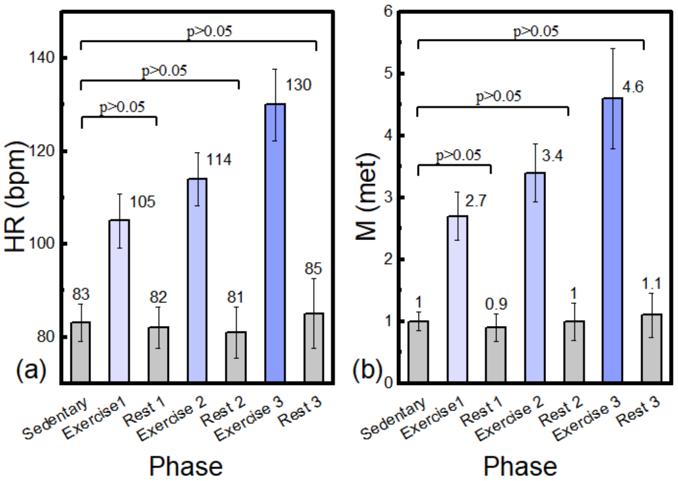

Fig 4. The heart rate (a) and metabolic rate (b) of the last record of the sedentary phase, exercise 1(3.0km/h walking exercise), rest 1, exercise 2(4.5km/h walking exercise), rest 2, exercise 3(6.0km/h walking exercise), and rest 3.

3.1.2 Skin temperature

A three-way repeated-measures ANOVA was performed on the Tskin. During the exercise phase, the thermal environment [F(5,414)=85.48, p<0.001, η2=0.74] and exercise duration [F(2.29,348.17)=6.49, P<0.001, η2=0.04] had a significant effect on Tskin, while exercise intensity [F(2,414)=1.67, P=>0.05, η2=0.02] did not. During the resting phase (12-24min), the thermal environment [F (5,414) =80.48, P<0.001, η2=0.73], exercise intensity [F(2,414)=3.83, P=<0.05, η2=0.05], and exercise duration [F(2.25,342.38)=9.94, P<0.001, η2=0.06] all had significant effects on Tskin. This suggests that thermal environment and exercise duration affected Tskin during both the exercise and rest phase, while the exercise intensity had a significant effect on Tskin only during the rest phase. Thermal environment had a more pronounced effect on Tskin than exercise duration and intensity.

The dynamic trend of Tskin is consistent across the thermal environment conditions [Fig. 5(a)]: during the exercise phase, Tskin decreases from 3 to 6 min after the start of exercise and continues to increase from 6 to 12 min during the rest phase. Tskin reaches its maximum value from 6 to 9 min after the start of rest, then gradually decreases. We conducted post hoc tests of Tskin to clarify the time taken for Tskin to stabilise. Exercise 1, 2, and 3 had non-significant (p>0.05) Tskin differences between 9 and 12 min after the start of exercise, which suggests that the Tskin had reached a stable level. Additionally, the working conditions had an effect on the amplitude of Tskin change for different exercises intensities during the exercise phase. In the thermal environment of -15 to 5℃, the maximum reduction of Tskin was the largest for exercise 1, followed by exercise 2 and exercise 3. The reduction of Tskin was close for the three exercise intensities at 15℃; the maximum reduction of Tskin at 25-35℃ was the largest for exercise 3, followed by exercise 2 and exercise 1.

During the exercise phase, Tskin fluctuations are predominantly associated with skin convective heat drainage and exercise metabolic heat generation [15, 63, 64]. In a hot environment, the area of skin covered by clothes is minimal. Convective heat dissipation from the skin surface due to quick walking at the beginning of the exercise phase is larger than exercise heat generation, resulting in the highest reduction in Tskin for exercise 3 and the least for exercise 1. In the low temperature environment, in which skin is totally covered by clothes, the convective heat dissipation in the walking process of the three exercise intensities is lower, while quick walking brings about more heat generation. Therefore, in the exercise phase, Tskin drop for exercise 3 is the least and for exercise 1 is the greatest. Tskin during the exercise phase is impacted by the combination of thermal environment, thermal resistance of clothing, exercise intensity, and exercise duration. In the rest phase, regardless of the thermal environment, the quicker the walking speed, the higher the maximal increase in Tskin. This is related to the continual thermal transfer from the body's core to the skin surface from heat generation after exercising, and the higher the exercise intensity, the higher the Tskin increase [47-49].

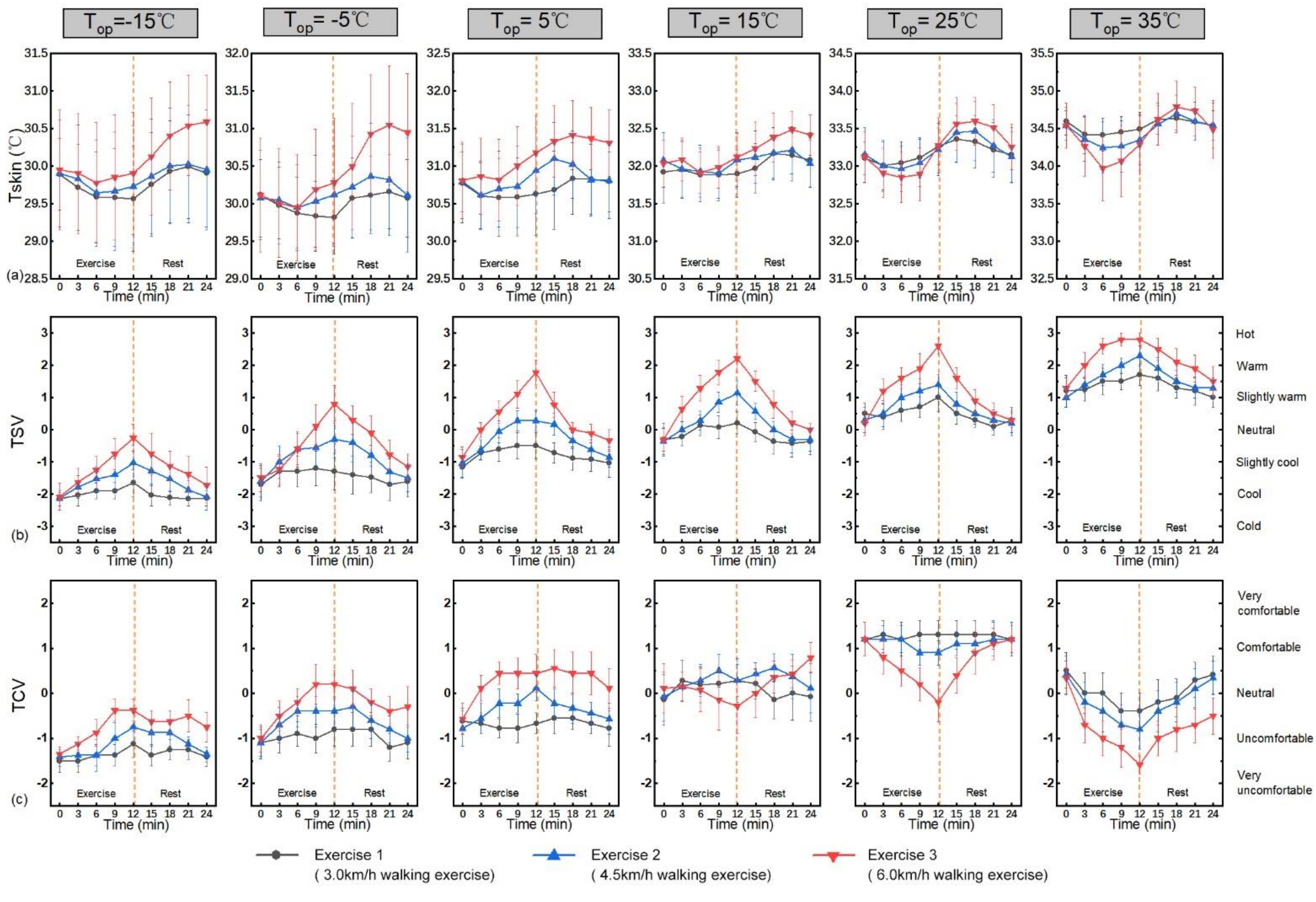

Fig. 5 Measured mean value and standard deviation (SD) of the skin temperature (Tskin) (a), thermal sensation vote (TSV) (b), thermal comfort vote (TCV) (c) under different exercise intensities and thermal environment.

One-way repeated-measures ANOVA was performed for the last record of Tskin at sedentary phase, exercise 1, rest 1, exercise 2, rest 2, exercise 3, and rest 3 to determine whether the Tskin at each phase was significantly different, as shown in Fig. 6. The results indicated that the change in physical activities significantly affected Tskin in six thermal environment conditions. For -15 to 15℃, the pair-wise comparisons showed no significant difference between the Tskin in rest 1, rest 2, and sedentary phase ($p>0.05$), while a significant difference between the Tskin in rest 3 and sedentary phase ($p<0.05$) was observed. For the thermal condition of 25-35℃, the pair-wise comparisons showed no significant difference between the Tskin in rest 1, 2, and 3, and sedentary phase (($p>0.05$). This indicates that in each of the environment conditions, the Tskin has been sufficiently reduced at the end of the rest phase of exercise 1 and 2, so as to not affect the results of the subsequent exercise phases. In future studies it should be noted that Tskin at 6km/h walking exercise in the environment of -15 to 15℃ failed to return to sedentary levels after 12 min of rest, and if additional experimental sessions were to follow, the rest duration would need to be increased.

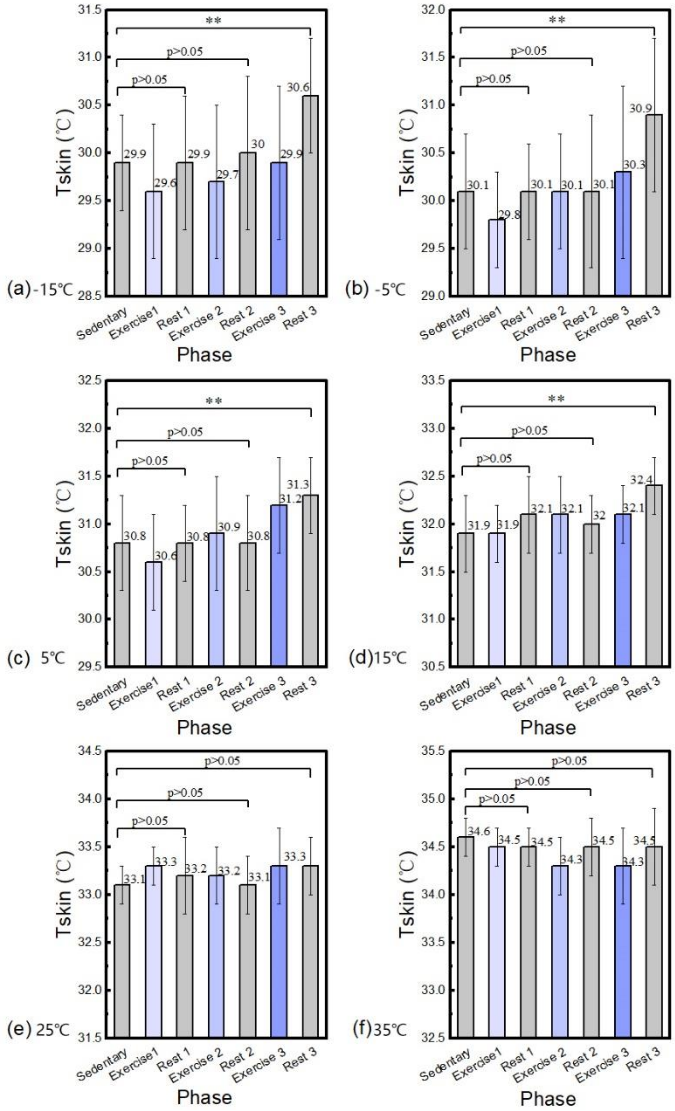

Fig. 6. The skin temperature of the last record of the sedentary phase, exercise 1(3.0km/h walking exercise), rest 1, exercise 2(4.5km/h walking exercise), rest 2, exercise 3(6.0km/h walking exercise), and rest 3 in different thermal environment.

3.2 Influencing factors and differences in psychological responses

3.2.1 Thermal sensation votes

According to the previous section, under the effect of stable exercise intensity and thermal environment, HR and MR reached stability at 6-12 or 9-12 min during exercise, and Tskin was stable at 9-12 min in the exercise phase. Two-way ANOVA was used to analyse the psychological responses during the stable state, with the mean value of TSV at minute 9 and 12 as the dependent variable, and exercise intensity and thermal environment as the independent variables, as shown in Fig. 7 and Table 5. The results indicated that the thermal environment had a significant effect on TSV, with TSV increasing as the ambient temperature increased, with exercise 1, 2, and 3 being the closest to a neutral thermal sensation at the operating temperatures of 15°C, 5°C, and -5°C, respectively. The exercise intensity also significantly affected TSV, with TSV increasing as the intensity increased; the higher the walking speed, the higher the TSV in the stable phase of movement in all thermal environment conditions. Compared to the sedentary phase, the mean increments in TSV for exercise 1, 2, and 3 were 0.5, 1.1, and 2.0 for all thermal conditions, respectively. There was no significant interaction effect (p>0.05) between exercise intensity and thermal environment (p>0.05). The thermal environment had the most pronounced effect on TSV, followed by exercise intensity.

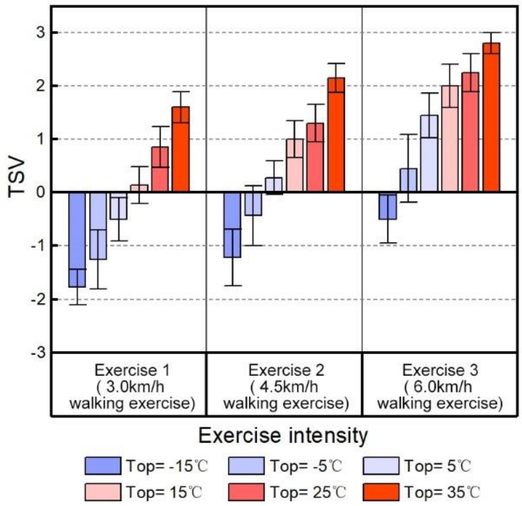

Fig. 7. Thermal sensation vote (TSV) of the subjects for Exercise 1, 2, and 3 in different thermal environment.

Table 5

Two-way ANOVA results for thermal sensation vote (TSV).

Source	SS	df	MS	F	P	η2
Thermal environment	253.370	5	50.674	70.158	0.000*	0.696
Exercise intensity	97.623	2	48.812	67.579	0.000*	0.469
Thermal environment * Exercise intensity	10.015	10	1.002	1.387	0.191	0.083

*p < 0.05 represents statistically significant difference. ANOVA: analysis of variance, df: degrees of freedom, SS: sums of squares, MS: mean squares, η2: effect size.

Regardless of the environment conditions, TSV increased gradually with exercise and decreased during the resting phase [Fig. 5(b)]. It is noteworthy that in all the conditions, TSV increased gradually at the beginning of the exercise and decreased gradually at the rest phase, while HR and MR increased rapidly at the beginning of the exercise phase, stabilised, decreased rapidly at the rest phase, then stabilised. This indicates that there is a certain lag in the change of TSV during exercise compared to the physiological response.

3.2.2 Thermal comfort votes

The TCV was analysed using the same methodology as in section 3.2.1, as shown in Fig. 8 and Table 6. The results indicated that the exercise intensity and thermal environment significantly affected TSV, and the interaction effect between exercise intensity and thermal environment was also significant. The thermal environment had the most pronounced effect on TCV, followed by interaction effect and the exercise intensity. The level of TCV was higher for higher exercise intensities in an environment condition of -15 to 5°C, lower for higher exercise intensities in the environment condition of 25 to 35°C, and close for different exercise intensities in the environment condition of 15°C. Of all six conditions, exercises 1 and 2 had the highest TCV levels at 25°C, which was 1.3 and 0.9, respectively (i.e., 'comfortable'), and exercise 3 had the highest TCV level at 5°C, which was 0.4 (i.e., 'neutral'). At 25°C, the mean values of TSV for exercises 1 and 2 were 0.9 and 1.3, respectively, which approximates to "slightly warm", while that for exercise 3 at environment condition of 5°C was 1.4, which approximates to "slightly warm". Therefore, the highest level of TCV was achieved when the TSV got "slightly warm". In terms of the dynamic trends in TCV, Fig. 5(c) shows a line graph of TCV over time. The dynamic change pattern of TCV varies from that of TSV, which displays a progressive rise with exercise independent of the exercise intensity and thermal environment, while the dynamic change trend of TCV changes according to the exercise intensity and thermal environment. During the exercise phase, the dynamic trend of TCV varies in different working conditions, with exercise 1 at 35°C, exercise 2 at 25°C and 35°C, and exercise 3 at 15-35°C, causing a decrease in thermal comfort levels. This also demonstrates that thermal comfort is determined by the combined effect of exercise intensity and thermal environment.

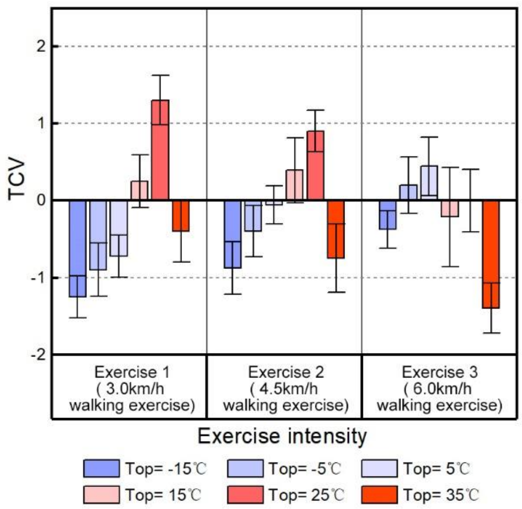

Fig. 8. Thermal comfort vote (TCV) of the subjects for Exercise 1, 2, and 3 in different thermal environment.

Table 6

Two-way ANOVA results for thermal comfort vote (TCV).

Source	SS	df	MS	F	P	η2
Thermal environment	51.314	5	10.263	14.552	0.000*	0.322
Exercise intensity	10.840	2	2.420	3.596	0.032*	0.018
Thermal environment * Exercise intensity	30.256	10	3.026	4.290	0.000*	0.219

*p < 0.05 represents statistically significant difference. ANOVA: analysis of variance, df: degrees of freedom, SS: sums of squares, MS: mean squares, η2: effect size.

3.3 Comparison of measured metabolic rate values with reference values of current normative

Standards for thermal environment and thermal comfort provide reference values for MRs at various exercise intensities, which are compared in Table 7. The reference exercise intensities given in these standards do not exactly correspond to the walking speeds chosen for this study (the values given in the specifications are bolded); therefore, the MRs corresponding to the walking speeds in this paper were calculated by interpolation and compared with the mean values of the steady phase (9 to 12 min) of exercise. It is noticeable that the recorded MR values during the stable phase of exercise are all higher than the levels stipulated in the standard. ISO 8996 underestimates MR values by 9.7% to 15.4% when compared to the measured MR values in this study, while ASHRAE 55 underestimates MR values by 25.0% to 50.0%. Because China's current GB 50785 data is taken from ISO 8996, the difference between the values measured in it and those measured in this study is the same as ISO 8996. The following is the regression equation for MR (MET) and the walking speed (V, km/h) generated using linear regression [Pearson correlation=0.910, Sig. (two-tailed) <0.001].

$$MR=0.6129*V+0.7653 \quad (R^2=0.8939)$$

Table 7

Comparisons of metabolic rate with thermal comfort standards (met)

	Sedentary	3.0km/h	3.2km/h	4.0km/h	4.3km/h	4.5km/h	5.0km/h	6.0km/h	6.8km/h
ASHRAE 55	**1**	1.8	**2**	-	**2.6**	2.7	-	3.6	**3.8**
ISO 8996	**1**	**2.4**	-	**2.8**	-	3.1	**3.4**	**3.9**	-
GB 50785	**1**	**2.4**	-	**2.8**	-	3.1	**3.4**	**3.9**	-
Measured (mean)	1	2.7	-	-	-	3.4	-	4.5	-

4. Discussion

4.1 The effects of exercise intensity and thermal environment in the thermal response during exercise

In terms of physiological response, exercise intensity and duration had a significant effect on HR and MR during moderate-to-high intensity exercise, while thermal environment had no significant effect. The higher the intensity of exercise, the higher the HR and MR values. Previous research on the effect of temperature on HR in sedentary populations found that ambient temperature had an effect on HR [44, 45], whereas research on moderate exercise populations found that exercise intensity and duration had a more significant effect on HR and MR [11, 14, 19]. This is because the body's thermophysiological response changes significantly when performing moderate-to-high intensity exercise, with the effects of differences in exercise intensity and duration on HR and MR far outweighing the effects of the thermal environment.

This study found that the thermal environment has a significant effect on Tskin during exercise, with Tskin increasing as ambient temperature rises, whereas exercise intensity has no effect, which is in line with Wang's [11] findings. On this premise, this study discovered that Tskin increases dramatically after the end of exercise, and the level of exercise has a substantial influence on Tskin: the stronger the exercise intensity, the higher the Tskin and the faster the Tskin warming rate, which is compatible with Li's [19] findings. This is related to the body's dynamic thermal equilibrium process during exercise, which produces a lag in Tskin to exercise changes. According to thermal physiology research, the body's core and skin exchange heat via direct contact and peripheral blood flow. The body's blood flow requirement for oxygenation of active muscles is high at the start of the exercise, resulting in vasoconstriction and reduced blood flow to the skin, and convective heat dissipation from the skin surface increases during exercise. Both of these work together to cause the Tskin to decrease at the start of the exercise. As the exercise continues, the high metabolic heat production raises the core temperature. At this point, the hypothalamus—the body's central control organ for thermoregulation—activates defence mechanisms. Blood vessels in the skin dilate, blood flow to the skin increases rapidly, and warmer blood is redirected from the core to the surface, thereby increasing the heat transfer from the core to the periphery, resulting in a decrease in core temperature and an increase in Tskin [46]. After activity, the warmer blood continues to flow from the core to the skin's surface, and the Tskin continues to rise; the more intense the exercise, the greater the core heat production and the higher the Tskin. With the end of the exercise, the cooled blood flows to the surface of the skin, where the Tskin rises to its highest point and gradually cools down and returns to the level of Tskin observed before the exercise began [47, 48, 49].

4.2 Characteristics of dynamic change and differences in thermal response during exercise

There was some variance in the characteristics of the physiological response to change during exercise in this study. Changes in HR were transient, with an immediate increase in HR after the start of the exercise, followed by a steady or significantly slower increase in HR, and an immediate decrease in HR after the end of the exercise, followed by a rapid return to the pre-exercise level of HR. As the MR is strongly related to HR, its dynamic trend of change is nearly synchronous. HR and MR reached a new steady state in 6 min for exercises 1 and 2, and 9 min for exercise 3. MR at steady state was 2.7±0.39 met, 3.4±0.47 met, and 4.5±0.81 met, respectively, for exercises 1, 2, and 3. In previous studies, Zhang et al. [26] monitored physiological indicators in participants walking at 1.2-2.0 m/s and discovered that HR increased rapidly at the start of exercise, stabilised after the third minute, decreased rapidly at the start of rest, and returned to levels comparable to those during sedentary periods within 10 min. Ji et al. [14] investigated MR during cycling exercise and discovered that MR fell rapidly within 5 min of activity and stabilised thereafter. Because of the variety in exercise intensity in the experiment, the duration for stabilising the HR and MR varied; however, all values increased rapidly and stabilised after the exercise, which is consistent with the conclusions of this paper.

In this study, Tskin gradually lowered 3-6 min after the start of the exercise, gradually climbed as the exercise continued, continued to rise after the exercise ended until 6-9 min later, and stabilised 9-12 min after the start of the exercise. According to Wang et al. [11], during exercise, Tskin drops before rising. Li et al. [19] assessed Tskin during basketball exercise and determined that it declined during the first 5-8 min of exercise and subsequently increased, with the Tskin increasing quicker at greater exercise intensities, and then began to decrease 8-10 min after the completion of the exercise. Because of changes in exercise intensity, the timing of change in Tskin differs from earlier research, although the general pattern is comparable with previous studies.

The psychological response was rather sluggish in comparison to the physiological response in this study; TSV and TCV did not increase or drop as quickly as HR and MR following a change in exercise status but spiked or declined gradually. This is congruent with Zhang's [15] findings, who discovered that changes in thermosensory polling lag behind changes in physiological responses, emphasizing the sluggishness of the psychological reaction during exercise [50]. Existing research suggests that Tskin influences heat sensation during exercise to some extent [18, 51, 52, 53, 54]. The findings of this study indicate that HR and MR are transient in nature; however, TSV and TCV are not, possibly due to the lagging nature of Tskin.

4.3 Differences in metabolic rate

In this study, ISO 8996 underestimated MR by 9.7% to 15.4% for moderate-to-high intensity exercise, while ASHRAE 55 underestimated MR by 25.0% to 50.0%. Previous research has revealed some inconsistencies between the MR in current standards and the actual measured values. ISO 8996 and ASHRAE 55, according to Nomoto et al., overestimate the MR for office activities (sitting, sedentary typing, standing) by roughly 15-32% [27]. According to Zhai et al. [25], current standards overestimate the MR for sitting and standing activities by 10 to 20% and underestimate the MR for walking at 2-5 km/h by 4-9%. Anand et al. [28] confirmed this in an environmental chamber experiment, where the actual MR was 128 W/m^2 (2.2 met) and 181.1 W/m^2 (3.11 met) at walking speeds of 2 km/h and 4 km/h, respectively, which is higher than the ISO 8896 values of 110 W/m^2 (1.9 met) and 165 W/m^2 (2.8 met), implying that ISO 8996 underestimates MR by 10.7% to 15.8%.

Individual variances are the main cause of variation. The MR described in ISO 8996, for example, is for a 'typical individual,' i.e., a male aged 30 years, weighing 70 kg, 1.75 m tall, with a body surface area of 1.8 m^2, and a female aged 30 years, weighing 60 kg, 1.70 m tall, with a body surface area of 1.6 m^2. The significant difference is that the respondents in this paper are approximately 4.5 weeks younger than the normative sample, as seen in Table 1. Furthermore, ethnic differences and lifestyle choices may have an impact on MR [27, 55, 56, 57]. The present criteria are based on 1960s European and North American population statistics and are still commonly utilised in thermal comfort evaluation studies globally, resulting in incorrect thermal comfort assessments. Instead of directly referencing the MR values in ISO 8996, the Chinese standard GB 50785 for the evaluation of interior temperature and humid environments in civil buildings should include standard criteria for MR based on the characteristics of the Chinese population.

4.4 Comparison between TSV and PMV

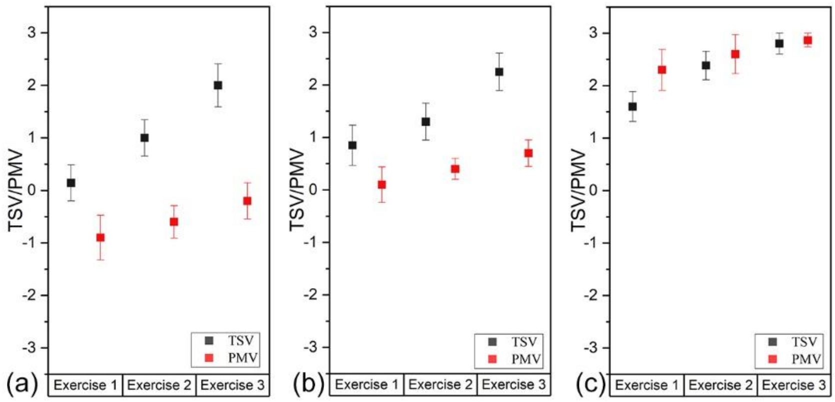

Fig. 9 The comparison between TSV and PMV in the environment of 15°C (a), 25°C (b), 35°C (c).

In this section, PMV values were calculated for 9 to 12 minutes of the exercise phase in 15, 25, and 35°C and compared to the collected TSV, as shown in Fig. 9 (Due to the requirement of PMV computation, the PMV values at -

15, -5 and 5°C cannot be determined [4, 41, 58], hence they are not incorporated in the comparison study). TSV was much higher than PMV in both the thermal environment of 15 and 25°C, whereas the difference between TSV and PMV was reduced in 35°C settings. In a similar study, Zhang et al. [15] found that PMV was too high to predict the TSVs of participants during the exercising period for walking speeds of 1.2 m/s, 1.4 m/s, and 1.6 m/s. The differences between TSV and PMV are caused by variances in thermal environmental adaptations, which derive from geographical differences and physiological restrictions [6, 31, 59]. The participants of this study are residents of a severe cold region, who are thus more adapted to low temperatures, and Zhang et al.'s [15] study was conducted in a subtropical climate region, where residents are more adapted to hot climates. Thus, the TSV of residents in severe cold regions were higher than PMV, and the TSV of residents in subtropical climate region were lower than PMV. In previous studies, Lam et al. [40] investigated the effect of physiological and psychological adaptation on overall thermal comfort, finding that physiological and psychological factors are essential to comprehend thermal perceptions. Jin et al. [30] concluded that the TSV and thermal acceptance of low temperatures were significantly higher in inhabitants of the severe cold than the Mediterranean regions, and the neutral temperatures in the transition and hot seasons were 21.4 °C and 21.8 °C UTCI (Universal Thermal Climate Index), respectively. Kumar et al. [60] found that Indians are adapted to higher temperatures, and the neutral temperature range was found to be 27.7-35.7°C UTCI. This is notably different from the results of studies in severe cold regions, which also discuss the effect of thermal adaptation on subjective thermal sensation.

4.5 Gender differences in thermal responses

Independent-samples t-tests were performed to test for gender differences in thermal response of participants in different exercise intensities and thermal environments in the stable state of the exercise phase; results are provided in Appendix B, Table B.1. The gender differences in thermal response were not substantial in this study, and only significant gender differences were reflected in Tskin. Table B.2 in Appendix B demonstrates the gender differences in mean Tskin in different thermal environments. In the low temperature setting (operative temperature: -15, -5, 5°C) male subjects' Tskin was greater than female participants', with a mean difference of 0.74°C. In the medium to high temperature environment (operative temperature: 15, 25, 35°C), male participants' Tskin was lower than female participants', with a mean difference of 0.27°C.

In earlier research, Fanger's [34] experiments revealed insignificant differences in TCV between male and female participants in the same environment with the same clothing thermal resistance, and other field studies [65, 66] did not observe gender-specific differences in thermal responses. However, some studies [67] revealed that women prefer slightly warmer environments than men. Zhao et al. [68] found that female participants' Tskin is more sensitive to thermal sensation than that of male participants under local cooling. The upper arm Tskin is most sensitive to thermal sensations for female participants, while the forearm Tskin is most sensitive for their male counterparts. Yang et al. [69] found that in cool conditions (14/16/18/20°C), women have lower Tskin compared to men, and in warm conditions (28/30/32/34°C), men's Tskin is slightly lower than women's. Women have lower metabolic heat-production capacity during cold exposures, men sweat more than women, and men's skin blood flow is higher than women's in warm exposures; these mechanisms dissipate the higher heat load more rapidly for men.

In general, from a physiological perspective, the MR of women is slightly lower than that of men during low-intensity activities, and women have lower Tskin, lower levels of thermal sensation, and a greater preference for higher temperatures than men. However, in medium to high intensity activities, women have lower sweating, and the difference in subjective thermal sensation and MR is not significant. Therefore, due to the combined effect of various factors, the relevance and intensity of gender effects on thermal responses need to be determined according to the real thermal environment and individual differences.

4.6 Limitations and future works

Due to the impact of the COVID-19 epidemic, access to college campuses was restricted; therefore, the respondents were all university students ranging in age from 23 to 32 years. Consequently, the results of this study are only applicable to the young population, and more research is needed to investigate the characteristics of thermal response during exercise in middle-aged and older adults. Furthermore, the impact of different elements influencing thermal response during exercise (including thermal expectation, emotion, weariness, and so on) is not clear, and future research should undertake additional experimental study. Lastly, this article and prior studies have discovered that individual differences in metabolism grow with exercise intensity, which will be examined further in future studies with larger sample sizes.

5. Conclusion

To investigate the effects of exercise intensity and thermal environment on thermal responses, college students were recruited to exercise at walking speeds of 3km/h, 4.5km/h, and 6km/h in six sets of thermal environment conditions with the operating temperature of -15 to 35°C. The dynamic trends, differences, and influence factors of physiological response (MR, HR, Tskin) and psychological response (TSV, TCV) during exercise were investigated. The main findings of this paper are as follows.

1. Regarding the role of exercise intensity and thermal environment in affecting thermal response, the exercise intensity had a significant effect on both HR and MR, whereas the thermal environment had no effect on either during the exercise. Tskin was dominated by the thermal environment, with exercise intensity having little effect that was only noticeable during the rest phase. This is because it takes time for core temperature heat production to continue to reach the skin, and the difference in core heat production due to exercise intensity is reflected at the end of the exercise. The effects of exercise intensity and thermal environment on psychological reaction (TSV and TCV) were both significant, with the thermal environment having a stronger influence.

2. In terms of the difference in physiological responses during exercise at different exercise intensities, within 3 min of starting the exercise, the HR and MR increase immediately, followed by a slow and steady increase during the subsequent exercise periods. Next, there is a rapid decline after stopping the exercise, and eventually, the HR and MR recover to sedentary levels. HR and MR reach a new stable level in 6 min for exercises 1 and 2, and 9 min for exercise 3. The more intense the exercise, the greater the HR and MR. The HR after stabilisation during the exercise was 99±6 bpm, 114±6 bpm, and 130±8 bpm, respectively, for exercises 1, 2, and 3, while the MR was 2.7±0.39 met, 3.4±0.47 met, and 4.5±0.81 met. Tskin drops for 6 min after starting exercise, then gently rises, reaching a peak around 9 min after the exercise stops, and then gradually drops. Tskin is stable between 9 and 12 min after starting the exercise.

As for the difference in psychological responses during exercise at different exercise intensities, regardless of the thermal environment conditions, the TSV rises progressively during the exercise period and declines gradually when the exercise ends. The higher the intensity of the exercise, the greater the TSV, with exercises 1, 2, and 3 raising TSV by about 0.5, 1.1, and 2.0, respectively, in comparison to sitting. At operating temperatures of 15, 5, and -5°C, respectively, exercises 1, 2, and 3 are closest to neutral thermal experience. TCV dynamics trends depend on thermal environment conditions. Exercise 1 at 35°C, exercise 2 at 25°C and 35°C, and exercise 3 at 15, 25, and 35°C all resulted in a decrease in TCV. TCV levels were higher for higher exercise intensities in the thermal environment of -15, -5, and 5°C, lower for higher exercise intensities in 25 and 35°C, and similar for different exercise intensities at 15°C. TSV and TCV do not change as quickly as HR and MR, and lag in comparison.

3. Current standards, to a certain extent, underestimate the MR of moderate-to-high intensity exercise. When compared with actual measured values, ISO 8996 and ASHRAE 55 underestimate the MR by 9.7% and 25.0% at least, correspondingly.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Thermal Responses Questionnaire during Exercising

Date:___/__/____

Part 1:

Gender: [A]Male/ [B]Female

Height(m):_______ Weight(kg):_______ Age:_____

What are you wearing right now:

[A] T-shirt [B] Shirt with long sleeves [C] Blouses with long sleeves [D] Sweater

[E] Thick sweater [F] Vest [G] Jacket [H] Coat [I] Parka [J] Shorts / short skirt

[K] Long pants / long skirt [L] Lightweight trousers [M] Flannel trousers

[N] Fiber-pelt trousers [O] Gloves [P] Cap

Part 2:

Number of questionnaires:_____ Time:___:___

1. Please describe your current thermal sensation:

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
− 3	− 2	− 1	0	1	2	3

2. Please describe your current thermal sensation:

Very uncomfortable	Uncomfortable	Neutral	Comfortable	Very comfortable
− 2	− 1	0	1	2

Fig. A. 1 Thermal responses questionnaire used in this study

Appendix B

Table B.1. Analysis of the difference of thermal responses among respondents of different genders.

Index	Thermal environment	Walking speed	t	Sig.(2-tailed)
HR	-15℃	3.0km/h	0.94	0.38
		4.5km/h	1.20	0.28
		6.0km/h	0.79	0.46
	-5℃	3.0km/h	-1.36	0.23
		4.5km/h	-1.36	0.23
		6.0km/h	0.04	0.97
	5℃	3.0km/h	-2.43	0.15
		4.5km/h	-1.74	0.12
		6.0km/h	-0.07	0.95

	15℃	3.0km/h	-0.14	0.89
		4.5km/h	-1.59	0.14
		6.0km/h	-0.57	0.58
	25℃	3.0km/h	-0.44	0.67
		4.5km/h	-2.79	0.12
		6.0km/h	-0.49	0.64
	35℃	3.0km/h	0.74	0.48
		4.5km/h	-0.26	0.80
		6.0km/h	0.28	0.78
MR	-15℃	3.0km/h	1.01	0.35
		4.5km/h	1.66	0.15
		6.0km/h	1.13	0.30
	-5℃	3.0km/h	-0.11	0.91
		4.5km/h	-0.11	0.91
		6.0km/h	1.20	0.28
	5℃	3.0km/h	-1.41	0.20
		4.5km/h	-0.53	0.61
		6.0km/h	1.00	0.35
	15℃	3.0km/h	1.02	0.33
		4.5km/h	-0.58	0.57
		6.0km/h	0.03	0.98
	25℃	3.0km/h	1.02	0.34
		4.5km/h	0.54	0.61
		6.0km/h	1.20	0.27
	35℃	3.0km/h	2.15	0.06
		4.5km/h	0.94	0.37
		6.0km/h	0.63	0.55
Tskin	-15℃	3.0km/h	3.42	**0.01**
		4.5km/h	4.73	**0.00**
		6.0km/h	4.75	**0.00**
	-5℃	3.0km/h	0.39	0.21
		4.5km/h	0.69	**0.04**
		6.0km/h	0.73	**0.03**
	5℃	3.0km/h	0.16	0.88
		4.5km/h	0.80	**0.05**
		6.0km/h	1.13	**0.01**
	15℃	3.0km/h	-0.45	0.66
		4.5km/h	-0.29	0.78
		6.0km/h	0.86	**0.03**
	25℃	3.0km/h	1.26	0.24
		4.5km/h	1.42	**0.04**
		6.0km/h	0.39	**0.01**
	35℃	3.0km/h	2.20	0.06
		4.5km/h	3.01	**0.02**
		6.0km/h	1.95	0.09

TCV	-15℃	3.0km/h	0.52	0.62
		4.5km/h	1.00	0.36
		6.0km/h	0.65	0.54
	-5℃	3.0km/h	-0.44	0.68
		4.5km/h	-0.44	0.68
		6.0km/h	-0.44	0.68
	5℃	3.0km/h	2.12	0.08
		4.5km/h	0.28	0.79
		6.0km/h	-1.01	0.35
	15℃	3.0km/h	1.07	0.31
		4.5km/h	2.48	0.13
		6.0km/h	1.95	0.18
	25℃	3.0km/h	-0.75	0.48
		4.5km/h	0.66	0.53
		6.0km/h	0.13	0.90
	35℃	3.0km/h	0.29	0.78
		4.5km/h	-0.13	0.90
		6.0km/h	0.93	0.38
TSV	-15℃	3.0km/h	0.00	1.00
		4.5km/h	0.88	0.41
		6.0km/h	0.00	1.00
	-5℃	3.0km/h	-0.72	0.50
		4.5km/h	-0.72	0.50
		6.0km/h	-0.56	0.60
	5℃	3.0km/h	0.92	0.39
		4.5km/h	0.64	0.54
		6.0km/h	1.65	0.14
	15℃	3.0km/h	0.28	0.78
		4.5km/h	-0.73	0.48
		6.0km/h	-1.47	0.17
	25℃	3.0km/h	0.00	1.00
		4.5km/h	0.53	0.61
		6.0km/h	-0.73	0.49
	35℃	3.0km/h	1.98	0.08
		4.5km/h	1.17	0.28
		6.0km/h	0.29	0.78

Table B.2. Mean skin temperature in different thermal environment and gender.

Thermal environment	Male	S. D.	Female	S. D.
-15	29.61	0.57	28.38	0.43
-5	30.39	0.67	29.73	0.39
5	30.94	0.43	30.62	0.5
15	32.13	0.38	32.34	0.29
25	33.05	0.47	33.33	0.53

35	34.31	0.31	34.64	0.34

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