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Original Research

Influence of Ambient Temperature on Autonomic Nerve Function and Peripheral Sensation from Moderate-Intensity Treadmill Exercise

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ABSTRACT

International Journal of Exercise Science 17(2): 491-503, 2024. Objective: The main objective was to ascertain the acute responses in autonomic nervous activity and peripheral sensation induced by moderate-intensity treadmill exercise performed under different ambient temperatures. Methods: Twelve young healthy subjects underwent three sessions of moderate-intensity treadmill exercise (warming, 5 min and running, 25 min), on different days under 10°C, 20°C and 30°C room temperatures. Pre- and post-intervention, heart rate variability (HRV) and plantar vibrotactile perception threshold (VPT) were measured. Additionally, rate of perceived exertion (RPE) was recorded after intervention. Results: In comparison with the corresponding baseline values, after intervention, low frequency power (LF) and LF/high frequency power (HF) of HRV increased significantly and HF decreased significantly under the condition of 10°C only ($p < .005$). Following intervention, VPT increased significantly at the hallux for 31.5 Hz test frequency under 30°C and at the heel for 31.5 Hz test frequency under 10°C (both $p < .05$). In contrast, VPT decreased significantly at the hallux for 125 Hz test frequency under 10°C ($p < .005$). Exposure under the temperature of 20°C did not result in any significant change in VPT. After intervention, RPE under 30°C showed significantly higher values than those under 20°C ($p < .01$) and 10°C ($p < .005$) conditions with no difference between the latter two conditions. Conclusions: Treadmill exercise under 20°C ambient temperature did not exert any negative impacts on autonomic and peripheral nerve function and resulted in a perceived exertion of moderate intensity among the study participants. Therefore, an ambient temperature around 20°C might be recommended for the mentioned purpose.

KEY WORDS: Exercise, room temperature, heart rate variability, vibrotactile sensation, exertion

INTRODUCTION

The available literature indicates that exercise can significantly influence nerve activity and various physiological responses in humans (1, 3). As a result, exercise can induce beneficial changes in the human body, and can be useful in the prevention of health disorders such as diabetes, osteoporosis, cardiovascular diseases, cancers etc. (41). Therefore, the habitual practice of moderate exercise is encouraged worldwide (14).

Exercise is performed under different ambient temperature conditions that may vary widely from about 7°C to 28°C (12), depending on the location and the season. However, for intervention with exercise, existing literature did not clarify the ambient temperature that can be considered useful and/or optimum for the purpose. As mentioned in the published literature, exposure to hot or cold ambient temperatures can create stress on the human body (42). Such exposures to unfavorable ambient temperature may cause disruption of different physiological systems with elevated risks for respiratory and cardiovascular diseases (10). On the other hand, the effects resulting from the combination of exercise with inappropriate ambient temperature on human health can become remarkably greater. And such combined exposure can impose severe stress on the autonomic nervous activity with a greater risk of succumbing to health injuries (2, 22, 37). Therefore, for the purpose of the prevention of such health injuries, it is important to investigate and elucidate the responses in autonomic nerve activity induced by exercise interventions combined with different ambient temperatures. But due to a lack of relevant investigations in the published literature, it is not clear how exercise under different ambient temperatures impacts the autonomic nervous responses such as the heart rate variability (HRV). Furthermore, relevant results existing in the published literature are not consensual or conclusive yet. For example, some studies exposing study participants to exercise reported improvements in HRV (11, 31), while others reported no change in it (18).

In the literature, it has been reported that ambient temperature can affect peripheral cutaneous sensation (13), and the balance of the human body is closely associated with plantar cutaneous sensation (24, 35). Treadmill training, on the other hand, influences human posture and body balance (4), and a decrease in plantar cutaneous sensitivity can lead to a decrease in body balance (24) or vice versa. Therefore, investigating treadmill exercise-induced changes in plantar cutaneous sensitivity under different ambient temperatures is important, as understanding these changes can aid in selecting the appropriate room temperature for interventions. Despite this importance, the alterations in peripheral cutaneous sensation from exercise performed under different ambient temperatures remain unclear. Revealing the responses in peripheral cutaneous sensation and also autonomic nerve function from such exposure under different temperatures and providing explanations of the probable underlying mechanisms may assist in implementing preventive measures against relevant health disorders. Additionally, it can contribute to recommending the optimal temperature for exposure to exercise interventions. However, the existing literature lacks information on the specific patterns of concomitant alterations in these parameters in the same subjects induced by the combined effects of exercise interventions and ambient temperatures. Investigating these interconnected dynamics will not only enhance our understanding of the intricate relationship between ambient temperature, exercise, and sensory functions but also contribute valuable insights for optimizing ambient conditions in different settings.

In this study, we aimed to investigate and clarify the acute effects of moderate-intensity treadmill exercise intervention conducted under different ambient temperatures on HRV, as well as vibrotactile perception threshold (VPT) of plantar foot among young healthy subjects. Additionally, we assessed the subjective perception of effort during intervention under each ambient temperature using a tool for rating of perceived exertion (RPE). We hypothesized that the ideal temperature/s would not adversely impact autonomic nervous activity and peripheral sensation, nor induce extreme fatigue among subjects exposed to moderate treadmill exercise.

METHODS

Participants

In this study, we adopted a single-group repeated measures research design and included healthy young subjects. For this, we calculated the sample size a priori with the software G*POWER ver. 3.1.9.7 (Universität Düsseldorf, Düsseldorf, Germany) for a repeated measure analysis of variance (ANOVA) test. The effect size was 0.25, power=0.80, α=0.05 and number of groups (conditions)=3. The computed sample size was 12 for each group (condition). The potential participants from Yamaguchi University School of Medicine were invited to this study by poster advertisements and words of mouth. The inclusion criteria for subjects were as follows: no history of cardiovascular, neurological, connective tissue or musculoskeletal diseases, or any other known disorders that would restrict exposure to treadmill exercise; no surgery during the previous year; non-smoker etc. Six male and six female volunteers were recruited for this study. The median (interquartile range/IQR) for age and body mass index were 21.0 (1.50) years and 19.3 (2.31) kg/m^2 for males, and 21.0 (1.25) years and 18.9 (4.03) kg/m^2 for females, respectively. We obtained written informed consents from all subjects before their participation in this research. The research protocol of this study complies with the Declaration of Helsinki and was approved by the ethics committee of Yamaguchi University School of Medicine (approval no. H2021-104, dated 22-09-2021). This research was conducted completely in accordance with the recognized ethical standards of International Journal of Exercise Science (27).

As instructed, subjects refrained from eating and drinking caffeine-containing beverages for at least 3 h, and intense physical activity or alcohol consumption for at least 12 h before the start of the experimental session. They were also advised to enter the laboratory after voiding, wear light clothing including two pieces for each of the upper and lower body parts, and be barefoot during the experimental session.

Protocol

Each experimental session was carried out randomly on different three days at least 24 h apart, during the fall season from October to November in 2021. To minimize the impacts of circadian rhythms on the physiological responses (6), the sessions were carried out for each participant approximately at the same time on different days between 9:00 am and 5:00 pm. During the experimental sessions, the measurements of HRV and VPT were conducted before and after the interventions. At the end of each session, RPE of each subject was evaluated.

All participants took off their shoes and socks prior to entering the laboratory. Subsequently, they underwent acclimatization to the room temperature for 15 min seated on a chair. The temperature of the experimental room was kept at any of the three experimental conditions, 10°C, 20°C and 30°C (±1°C), for at least 1 h prior to the start until the end of each session. The average relative humidity of the room was around 50% during the experimental sessions (9). During acclimatization, the subjects placed their hands on the corresponding thighs; their feet was positioned on the wooden floor. Normal arm blood pressure was confirmed at 10th min of acclimatization.

After the acclimatization, we performed the baseline measurements of VPT. Subsequently, the subjects were instructed to stand on the treadmill (MS194176, BTM, China) facing forward and keeping the upright posture. All participants were instructed to let both arms hang down, positioned in close contact with their trunk, in a relaxed manner. After resting for at least 1 min, HRV was measured for 5 min. Subsequently, the subjects underwent the exercise intervention that included a primary warm-up running on treadmill for 5 min at 2 km/h, and then running for 25 minutes at a constant speed, set at 50-70% of their individual heart rate reserve. For the calculation of the target heart rate for each subject, the following equation based on Karvonen's formula was employed (11, 16):

[(220 - age - resting heart rate) × (0.5 to 0.7) + resting heart rate].

At the end of exercise intervention, the participants kept their upright posture, and the measurement of HRV was conducted for 5 min. Following this, they were instructed to sit back, and the measurements of VPT were performed. Lastly, we collected the RPE data with the Adult OMNI-Walk/Run Scale, and the experimental session ended. In this study, all the study participants could complete all the experimental sessions.

To collect the HRV data, we used a 2-channel heart rate device (CheckMyHeart, DailyCare BioMedical, Inc., Taiwan) connected via electrode cables (Bioload SDC-H, GE Healthcare, Japan) with disposable Ag/AgCl circular surface electrodes (Bioload SDC-H, GE Healthcare, Japan). The electrodes were placed on the ventral forearms of the subjects. For analysis of the HRV data, a sampling frequency of 250 Hz was used (20). The HRV data were visually verified for ectopic beats or artifacts utilizing an analysis software (DailyCare BioMedical, Inc., Taiwan). Subsequently, very low frequency power (VLF, 0.0033 to 0.04 Hz), low-frequency power (LF, 0.04 to 0.15 Hz) and high-frequency power (HF, 0.15 to 0.40 Hz) components of frequency-domain measures of HRV were calculated. For this purpose, fast‐Fourier‐transformation was used and detrended values from the normal RR intervals were calculated. To obtain the LF and HF values in normalized units (nu), the following formulas were used: (1) LF (nu) = LF ÷ (total power - VLF); and (2) HF (nu) = HF ÷ (total power - VLF).

VPT (expressed in m/s^2) were recorded at two plantar locations: the hallux and the heel of each subject's right leg. For the measurements of VPT, we used a vibrotactile perception meter (VPM, HVLab, University of Southampton, UK), and two test frequencies of 31.5 Hz and 125 Hz. The measurements were taken in accordance with the protocol stated in the international standard

ISO 13091-1 (2001) (15). We randomized the test locations and test frequencies for each subject. During the measurements of VPT, the subjects sat comfortably on a chair with eyes open and placed their right hand on the corresponding thigh. Their left foot was positioned on the wooden floor, while the right foot was placed on the vibration probe that was fixed approximately 4 cm above the floor (23). The switch of the VPT device was held by the subject's left hand. The participants were instructed to hold the measurement site of the right foot over a cylindrical vibration probe and to maintain a surround contact force of approximately 2 N. The diameter of the probe and probe-surround gap were 6 mm and 2 mm, respectively. The digital scale of VPM displayed the applied force. The vibration stimuli were delivered perpendicularly to the subjects' skin surface via the stimulation probe, in increasing and decreasing patterns according to von Bekesy up/down psychophysical algorithm, at a fixed rate of 3 dB/s (23). When the stimulus was perceived at the test location, the response button was pressed by the left thumb of the subject and the button was released when the stimulus was no longer felt. The sequence was repeated at least six times for each test frequency. For calculation of the VPT value, the mean of the corresponding peak (ascending) and trough (descending) threshold values was used. During the VPT test, the vibrometer display could be seen only by the experimenter.

To monitor the room temperature, a digital thermistor (SZL-64, Technol seven, Japan) was used. It was connected to a high accurate data logger (K730, Technol seven, Japan) and scanner (X115, Technol seven, Japan). The measurement accuracy was ±0.15°C. Indoor relative humidity was measured using a commercial heat index meter (WBGT-101, Kyoto Electronics Manufacturing Co. Ltd., Japan). RPE was evaluated with the Adult OMNI Walk/Run Scale. This is an 11-point scale and rated from 0 to 10.

Statistical Analysis

Shapiro-Wilk tests were performed to verify the normal distribution of the collected data. Accordingly, the continuous variables of this study have been shown as median with 25th and 75th percentiles in the figures (for HRV and VPT) or mean with standard error (for RPE). The differences between the measurements were assessed by Wilcoxon signed-rank tests and univariate repeated measures ANOVA with Bonferroni corrections for multiple comparisons, as necessary. Effect sizes were calculated by matched-pairs rank biserial correlation for Wilcoxon signed-rank tests (17) and partial eta-square for repeated-measures ANOVA (30). We used the software package SPSS version 22 for Windows (SPSS Inc., Chicago, IL, USA) for the statistical analyses. All the statistical tests were two-tailed; the significance level was set at $p < .05$.

RESULTS

Figure 1 represents the before- and after-intervention values of HRV parameters, i.e. LF (nu), HF (nu) and LF/HF for three different conditions of ambient temperature. As observed, the measured LF (nu) and LF/HF values obtained before intervention under 10°C condition were significantly lower and the value of HF (nu) was significantly higher than those derived for 20°C and 30°C ambient temperatures, respectively (effect sizes -0.56 to -0.61, $p < .05$ to $.01$). But no significant differences were observed in these three parameters of HRV between the latter two conditions. While the after-intervention values of HRV were compared to the corresponding baseline values, a general trend was observed with an elevation in LF (nu) and LF/HF, and a reduction in HF (nu) under three different temperature conditions. However, such changes in HRV, after intervention, were found to be significant under 10°C only (effect size -0.62, $p < .005$).

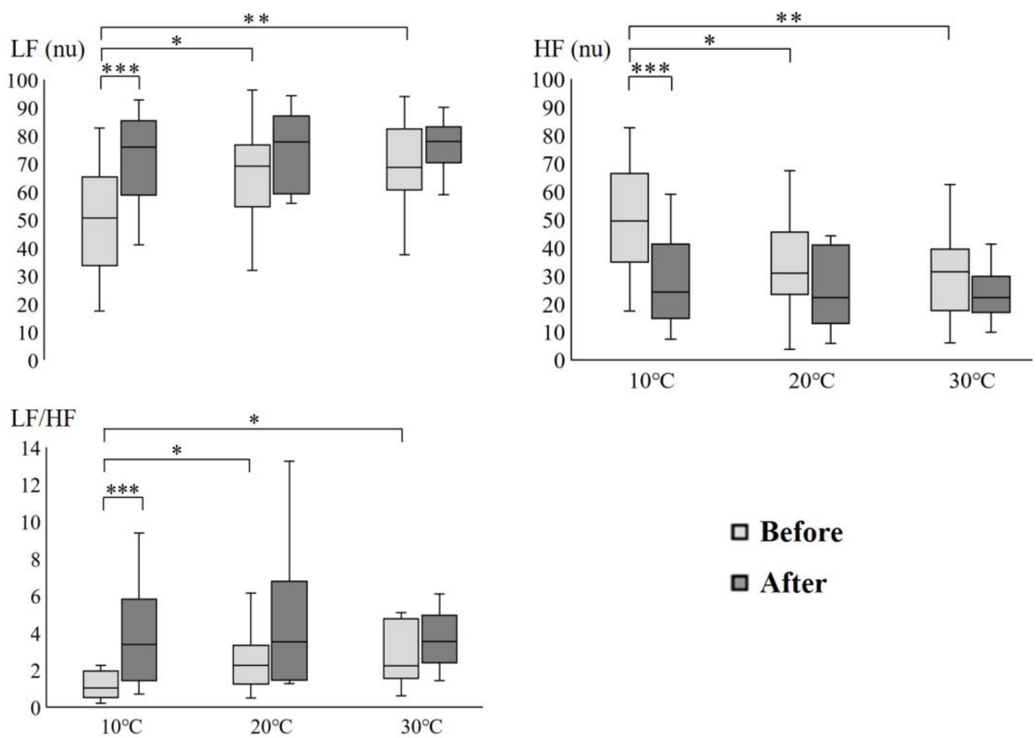

Figure 1. Boxplots of LF (nu), HF (nu) and LF/HF before and after intervention under 10°C, 20°C and 30°C ambient temperatures are shown. Boxplots display the median values with corresponding 25th and 75th percentiles for the measured HRV parameters. Levels of significant differences between baseline values, and between before and after intervention values: * $p < .05$, ** $p < .01$ and *** $p < .005$.

Figure 2 represents before- and after-intervention values of VPT derived for different ambient temperature conditions, recorded at plantar aspects of hallux and heel of right foot, for both test frequencies. When the before-intervention values were compared, VPT under 10°C condition showed a significantly higher value than the values recorded under the two other temperature (20°C and 30°C) conditions, at both test locations and test frequencies (effect sizes -0.57 to -0.62, $p < .05$ to .01) except at the heel for 31.5 Hz test frequency. No significant difference could be observed between the VPT values obtained under 20°C and 30°C temperature conditions. Compared to the corresponding before-intervention value, after intervention, VPT at the hallux increased significantly under 30°C for the test frequency of 31.5 Hz (effect size -0.45, $p < .05$). In contrast, at the same location, VPT at 125 Hz test frequency showed a significant decrease under 10°C (effect size -0.62, $p < .005$). At the heel after intervention, when the corresponding before- and after-intervention values were compared, the only significant change (increase) in VPT was observed at the heel under 10°C at the test frequency of 31.5 Hz (effect size -0.44, $p < .05$).

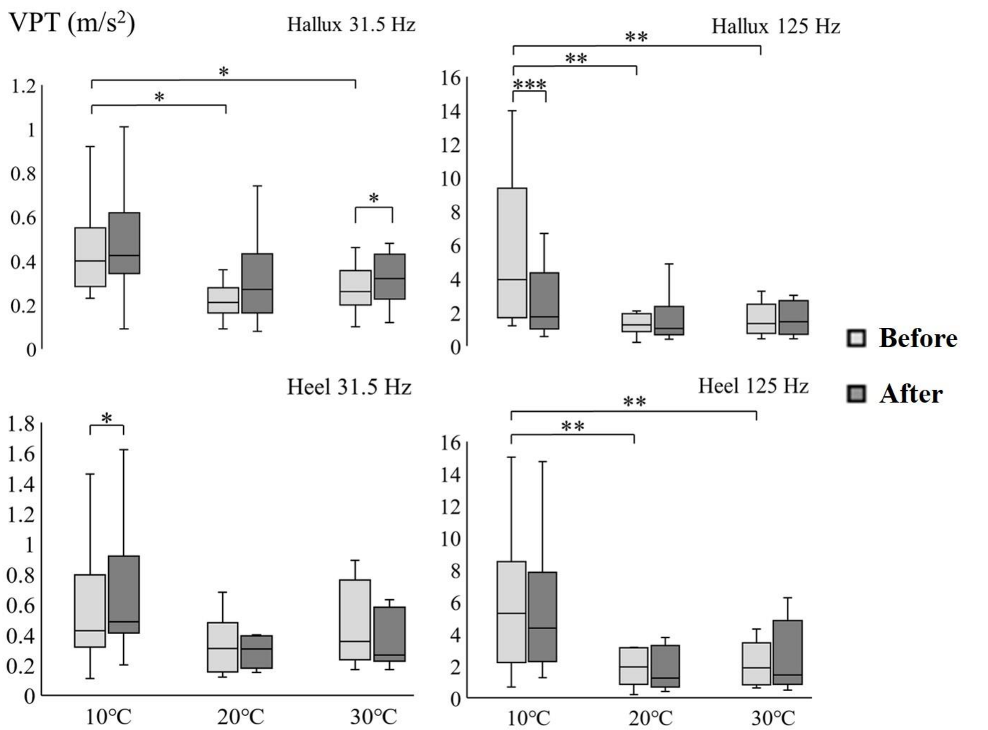

Figure 2. Boxplots of VPT (m/s²) at the hallux (upper row) and heel (lower row) before and after intervention under 10°C, 20°C and 30°C ambient temperatures obtained for the test frequencies of 31.5 Hz and 125 Hz (left and right panels, respectively). Boxplots display the median values of VPT with corresponding 25th and 75th percentiles. Levels of significant differences between baseline values, and between before and after intervention values: * $p < .05$, ** $p < .01$ and *** $p < .005$.

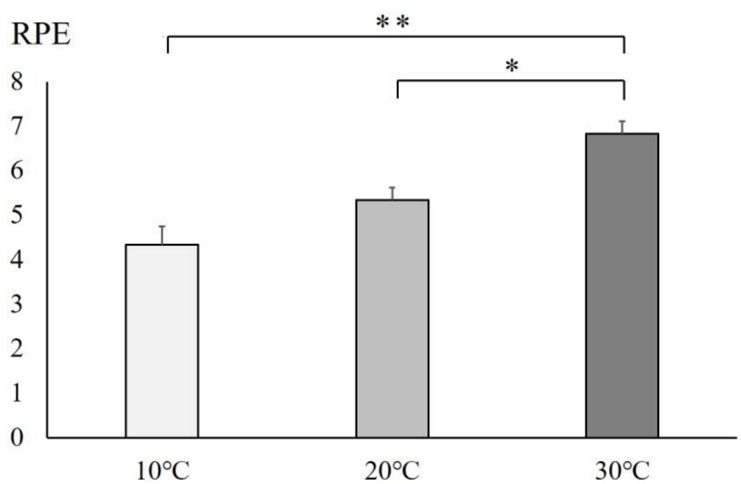

Figure 3. RPE scores obtained under 10°C, 20°C and 30°C ambient temperature conditions. The values have been presented as mean and SE (error bars). Levels of significant differences have been indicated as * $p < .01$ and ** $p < .005$ versus 20°C and 10°C, respectively.

Figure 3 represents the values of RPE under the conditions of 10°C, 20°C and 30°C ambient temperatures. Comparison of the values under three conditions revealed that the RPE under 30°C (6.8 ± 0.3) was significantly elevated than that under 20°C (5.3 ± 0.3) and 10°C (4.3 ± 0.4) conditions (effect size 0.47, $p < .01$ and $< .005$, respectively). However, no significant difference could be revealed between the values obtained under 10°C and 20°C ambient temperature conditions.

DISCUSSION

Treadmill exercise has been widely acknowledged for its potential to elicit numerous beneficial effects on the human body (29). In light of this, our study aimed to clarify and confirm the changes in autonomic nervous activity and peripheral sensation in response to moderate-intensity treadmill exercise under ambient temperature variations.

In our study, we performed short-term (5 min) recordings of HRV. Such a measurement duration is a standard option for analysis of collected HRV data (38). For characterization of HRV, we measured its widely used frequency-domain components which allow the quantification of RR intervals by using their cyclic variation (5). Among the frequency-domain components of HRV, LF reflects both sympathetic and parasympathetic nervous tone, HF is an index showing purely parasympathetic tone, and LF/HF represents sympathovagal balance (38). We used relative (normalized) powers of LF and HF which could remove a considerable amount of within and between-subject variability in the raw HRV spectral power and allowed direct comparisons between measurements of HRV (38). In the current study, compared to 20°C or 30°C experimental conditions at baseline, we observed significantly lower values of LF (nu) and LF/HF, and higher values of HF (nu) under 10°C condition. These findings indicate a reduced sympathetic and an enhanced parasympathetic tone at rest under 10°C condition. It might be possible that whole-body cold exposure during acclimatization to room temperature in resting posture influenced autonomic nervous system (ANS) with increased vagal activity and shifted it towards parasympathetic dominance (19). However, after intervention with exposure to treadmill exercise, we observed significant increases in LF (nu) and in LF/HF, and a decrease in the values of HF (nu), only under 10°C condition. As suggested, exercise under whole-body cold exposure conditions can cause predominantly sympathetic activation which can be coupled with an increased cardiovascular burden from such exposure (2, 22). Sanchez-Gonzalez and Figueroa (2013) mentioned that compared to temperate conditions, cold exposure can cause an attenuation in post-exercise cardiovagal reactivation and sympathetic withdrawal (33). Considering the findings of others and those of ours on exercise-induced changes in HRV under different ambient temperatures, we hypothesize that moderate-intensity treadmill exercise caused a decrease in HRV under 10°C with augmented sympathetic activity and its relative predominance, and an attenuation of the parasympathetic reactivation (2, 22, 33). In other words, exposure to treadmill exercise of moderate intensity under 20°C and 30°C appeared to be less stressful to the study participants. An exercise modality is desirable that would not adversely influence HRV by causing a reduction in the latter. This is because a reduced HRV can be associated with a dysfunction in the ANS which may lead to adverse health effects (21). Therefore, the ambient temperatures, 20°C and 30°C, seem to be preferable to 10°C for the mentioned purpose.

The plantar cutaneous sensation is likely to change depending on the sole-to-platform contact forces (43), and the influence of walking/running on such sensation is expected to be stronger at the hallux and heel (26). Therefore, in the present study, we performed the measurements of VPT at these two locations. Also, for measurements of VPT, we used 31.5 Hz and 125 Hz as the test frequencies which represent the Meissner's and Pacinian corpuscles, respectively (13). In this study, we observed a significantly higher baseline VPT under 10°C compared with that under the 20°C and 30°C ambient temperatures, which might have been caused by a reduction in cutaneous sensitivity with decreased skin temperature from exposure to lower ambient temperature (13). As our results show, the patterns in exercise-induced responses in VPT differed between 31.5 Hz and 125 Hz test frequencies. Our findings on VPT cannot be compared with those of others due to the lack of studies investigating similar changes in the former as a result of exposure to treadmill exercise under the condition of multiple ambient temperatures. However, the observed differences in exercise induced VPT responses at two test frequencies probably reflect diverse densities and different functions of the mechanoreceptors responsible for vibration perception at the test sites (36). After intervention, an unexpected finding was a significantly reduced level of VPT at 125 Hz in the hallux under the exposure condition of 10°C. It is difficult to explain the underlying mechanisms for such an observation due to our study design and a lack of relevant published literature. However, Schmidt et al. (2016) observed that treadmill exercise for a duration of 30 min improved planter sensitivity of Pacinian corpuscles at the hallux and first metatarsal head (34). The authors of that study explained such an improvement in plantar sensitivity as a combined effect of mechanical stimulation of the foot with an enhancement in plantar afferent feedback and an elevation in skin temperature resulting from an exposure to treadmill exercise (34). In a previously published study, we also reported an increase in foot skin blood flow that was induced by exercise on a treadmill (40). Therefore, we postulate that a significantly higher baseline VPT with a greater scope for changes in the latter and an increase in treadmill exercise-induced foot skin circulation might have contributed to such an improvement in VPT at the hallux under 10°C. On the other hand, as we could not see any exercise-induced changes in VPT at any test frequency or location under the exposure condition of 20°C, it might indicate that a temperature of 20°C which lies within the range of thermoneutral zone of clothed humans (8), caused the minimal changes on mechanoreceptor perception among subjects exposed to moderate-intensity treadmill exercise. In contrast, the observed increase in VPT under 10°C and 30°C exposure conditions might indicate that exposure to the same treadmill exercise can induce a decrease in mechanoreceptor perception under lower and higher ambient temperatures.

Assessment of RPE using the OMNI scale has been shown to be useful for the evaluation of the intensity for treadmill exercises in adults (39). In our study, RPE was significantly higher under 30°C than that under the other two ambient temperature conditions. As our RPE results show, the intensity of the applied treadmill exercise under 10°C and 20°C temperature conditions was perceived as moderate as opposed to the intensity, which was found to be high under 30°C condition (25). Our findings correspond with those of Galloway and Maughan (1997) where young healthy male subjects performed prolonged cycle exercise to exhaustion at ambient temperatures of 3.6 ± 0.3°C, 10.5 ± 0.5°C, 20.6 ± 0.2°C, and 30.5 ± 0.2°C (7). In that study, overall

RPE was significantly higher during the intervention under 30.5°C compared with all other ambient temperature conditions (7). Also, our observations correspond well with those of Ruddock et al. (2017) who mentioned that RPE is related to heat perception, and compared to higher ambient temperatures, aerobic exercises are easier to perform under lower temperatures (32). In contrast, Potteiger and Weber (1994) observed no significant differences in RPE across temperature conditions of 14°C, 22°C and 30°C among young male subjects exposed to constant load exercise till exhaustion (28). Such a difference in the observed results might have been caused by the fact that cyclists were recruited in the latter study who probably had higher tolerance to exertion. Our findings also indicate that moderate-intensity treadmill exercise caused similar level of fatigue under 10°C and 20°C ambient temperatures, as felt by young healthy adults.

Several potential limitations exist to the current study and hence, cautions are needed in interpreting the study results. The present study was performed among young adults who were apparently healthy; therefore, the observed findings of this study cannot be generalized to other populations. While our study involved a modest number of subjects, conducting a broader investigation with a larger sample would be valuable in enhancing the robustness and confirmation of our results. In this study, the focus of the investigation was on the acute influence of treadmill exercise intervention on autonomic nerve function and peripheral sensation. In contrast, sports and exercise centers usually use exposure to treadmill as long-term chronic interventions. Despite this, our current findings have implications for understanding the effects of moderate-intensity treadmill exercise on autonomic nerve activity and peripheral sensation under different ambient temperatures. In future, the changes in autonomic nerve function and peripheral sensation from repeated long-term treadmill exercise to different intensities need to be investigated among subjects of different age groups.

Conclusions: In the current study, we ascertained the acute responses in autonomic nervous activity and peripheral sensation induced by moderate-intensity treadmill exercise that was conducted under three different ambient temperatures. Treadmill exercise under 20°C temperature condition did not cause any adverse change in autonomic nervous activity and foot cutaneous sensation. Also, treadmill exercise under the same temperature was perceived as less intense compared to that under the higher temperature. Considering all these, we conclude that an ambient temperature around 20°C might be recommended while using treadmills as indoor exercise tools.

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