

Effects of intermittent pinpoint thermal stimulation using electronic moxibustion on cardiovascular responses: a randomized crossover study

Kojiro Ito

Kojiro_ito@morinomiya-u.ac.jp

Morinomiya University of Medical Sciences

Hidehiro Nakahara

Morinomiya University of Medical Sciences

Research Article

Keywords: Moxibustion, Pinpoint thermal stimulation, Heart rate, Blood pressure, Skin temperature

Posted Date: October 16th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10136791/v1>

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Additional Declarations: No competing interests reported.

Abstract

Background

Moxibustion is a traditional therapeutic modality in which localized, pinpoint thermal stimulation is applied to specific cutaneous sites (acupoints). Although used for cardiovascular conditions, the physiological responses to such spatially restricted thermal stimulation remain insufficiently understood, particularly in comparison with large-area heating that delivers broader thermal input. In particular, it remains unclear whether the temporal pattern of stimulation influences sustained cardiovascular responses, which is important for the development of effective stimulation protocols and potential clinical application. The present study examined the effects of pinpoint thermal stimulation, mimicking moxibustion, on cardiovascular responses using a two-stage design.

Methods

Twenty-nine healthy students participated in this study. Study 1 ($n = 14$) consisted of a 3-min baseline period (Pre) followed by 3 min of continuous thermal stimulation (Stim). Study 2 ($n = 15$) used a randomized crossover design with control (CL) and intermittent thermal stimulation (TL) conditions, each including a 5-min Pre and a 5-min intervention period (Stim). Thermal stimulation was applied to the Zusanli acupoint (ST36) using an electronic moxibustion device with a ceramic 2-mm tip. Heart rate (HR), mean blood pressure (MBP), and skin temperature (SKT) were continuously recorded. Heart rate variability (HRV) indices were analyzed in Study 2. Data were analyzed using one-way or two-way repeated-measures ANOVA.

Results

In Study 1, HR decreased during stimulation associated with increased SKT, but returned toward baseline during continuous stimulation ($p < 0.001$). In Study 2, HR decreased during Stim in the TL condition accompanied by increased SKT, and was maintained throughout the intervention period. Significant Condition $\times$ Time interactions were observed for HR ($p = 0.001$), SKT ($p < 0.001$), high-frequency power in normalized units (HFnu) ($p = 0.019$), and low frequency/high frequency (LF/HF) ratio ($p = 0.002$). No significant interaction was observed for MBP.

Conclusion

Pinpoint thermal stimulation reduced HR associated with increase in local SKT. This response was transient during continuous stimulation but was sustained during intermittent stimulation, indicating that the temporal pattern of stimulation influences the persistence of cardiovascular effects. This study

provides a physiological basis for and may support the development of clinical application of pinpoint thermal stimulation.

Trial registration

The University Hospital Medical Information Network Clinical Trials Registry, UMIN000062912, Date: 2026-9-15, Retrospectively registered.

Background

Moxibustion is a traditional therapeutic modality in which transient thermal stimulation is applied directly or indirectly to specific cutaneous sites known as acupoints. In clinical practice, this therapy has been used as an alternative approach for conditions involving impaired physiological regulation, including chronic fatigue, arteriosclerosis, and hypertension [1–3]. However, many of these applications rely on empirical knowledge, and the underlying physiological mechanisms have not been sufficiently elucidated. Further basic evidence is therefore required to support its clinical application.

Indirect moxibustion has gained attention as a method for delivering thermal stimulation without causing direct tissue damage. In our previous study, an increase in local skin temperature immediately after stimulation onset was accompanied by a reduction in heart rate (HR), and this response diminished as the local temperature declined during stimulation [4]. These findings suggest that localized thermal stimulation may influence cardiovascular regulation through changes at the stimulation site rather than through systemic heating.

Thermal interventions applied over a large area, such as Waon therapy [5] and heat-and-steam generating (HSG) sheets [6, 7], have been reported to induce cardiovascular responses. However, these approaches involve relatively broad heating, and the effects of localized thermal input, as in moxibustion, remain unclear.

Localized heating of the skin generates spatially confined afferent input through thermosensitive receptors [8]. The characteristics of this input likely differ from those induced by large-area heating, depending on the spatial distribution of the stimulus. Moxibustion, with its small contact area and steep temperature gradient at the skin surface, may therefore provide a distinct form of sensory input.

Despite these features, the effects of localized thermal stimulation on cardiovascular responses have not been sufficiently examined. In particular, it remains unclear whether such stimulation can induce sustained changes in cardiovascular variables. In our previous observations, the reduction in HR was transient and diminished gradually during continuous stimulation. This may reflect an adaptive property of thermosensitive afferent pathways, in which responsiveness decreases during sustained stimulation.

The present study focused on pinpoint thermal stimulation that mimics moxibustion and examined its effects on cardiovascular responses. The study was conducted in two stages. In Study 1, continuous

stimulation was applied to characterize the basic response. In Study 2, the stimulation protocol was modified to an intermittent pattern by periodically moving the device vertically toward and away from the skin surface, with the aim of sustaining the response observed in Study 1. We hypothesized that intermittent stimulation would maintain the HR reduction observed during continuous stimulation. Mean blood pressure (MBP) was also evaluated to further characterize cardiovascular responses. These findings may contribute to understanding the physiological basis of moxibustion and its potential application as a non-invasive method for cardiovascular modulation.

Methods

This study took place in a laboratory room of the Morinomiya University of Medical Sciences, Japan, from October 2022 to November 2025. The article was written in accordance with the CONSORT 2010 statement.

Participants

A total of 29 healthy university students participated in this study. Fourteen participants (7 males and 7 females; age: 19.8 ± 1.6 years; height: 161.7 ± 9.9 cm; body mass: 58.2 ± 11.1 kg; BMI: 22.0 ± 1.9 kg/m²) were included in Study 1, and 15 participants (8 males and 7 females; age: 20.1 ± 1.5 years; height: 167.9 ± 6.9 cm; body mass: 62.3 ± 10.7 kg; BMI: 21.9 ± 2.3 kg/m²) in Study 2. The sample size was determined based on the number of volunteers available to participate in the study.

All participants had no history of cardiovascular, neurological, and respiratory disorders, and were not taking any medications known to affect autonomic or cardiovascular function. Participants were instructed to abstain from caffeine, alcohol, and strenuous physical activity for at least 12 hours prior to the experiment. Written informed consent was obtained from all participants before participation. The study protocol was approved by the Ethics Committee of Morinomiya University of Medical Sciences (approval no. 2019-057) and conducted in accordance with the principle of the Declaration of Helsinki.

Experimental design and protocols

This study consisted of two experiments: Study 1 (exploratory experiment) and Study 2 (controlled experiment). All experiments were conducted in a quiet, temperature-controlled laboratory environment ($24 \pm 1^\circ\text{C}$), with participants resting in the supine position throughout the protocol.

Study 1 was conducted to examine the acute cardiovascular responses to continuous thermal stimulation. Upon arrival at the laboratory, participants rested quietly in the supine position for 10 min to achieve a stable baseline condition. Subsequently, participants underwent a single session consisting of 3-min resting baseline period (Pre) followed by a 3-min continuous thermal stimulation period (Stim), as shown in Fig. 1.

Study 2 was a randomized crossover trial with two experimental conditions: a control condition (CL: no heating) and a thermal stimulation condition (TL), as shown in Fig. 2. The order of the conditions was randomized by drawing concealed slips from an envelope. Participants drew a slip and immediately handed it to the investigator without viewing its contents. The condition indicated on the slip was performed first, followed by the other condition in the subsequent session. Thus, participants were unaware of the assigned condition until the intervention was initiated. Because of the nature of the interventions, neither the participants nor the investigators could be blinded during the intervention. Each condition was performed on a separate day, with an interval of at least one week between conditions. Both conditions were conducted at the same time of the day for each participant to minimize circadian influences.

Upon arrival at the laboratory, participants rested quietly in the supine position for 10 min prior to each experimental session. Each condition consisted of a 5-min resting baseline period (Pre) followed by a 5-min intervention period (Stim), as shown in Fig. 3. In both conditions, the device was moved vertically at regular intervals to minimize potential mechanical stimulation. In the TL condition, thermal stimulation was applied, whereas in the CL condition, the heating function was turned off.

Thermal stimulation

Thermal stimulation was applied using an electronic moxibustion device (CQ5000, Murata, Kyoto, Japan) as shown in Fig. 4. The tip of the device was made of ceramic with a diameter of 2 mm. All stimulations were administered by a single trained investigator to ensure consistency. The stimulation site was the Zusanli acupoint (WHO; ST36) on the left leg, which has been used in our previous studies demonstrating cardiovascular responses to thermal stimulation [4, 9].

In Study 1, continuous pinpoint thermal stimulation was applied by maintaining constant contact between the device and the skin surface throughout the stimulation period.

In Study 2, intermittent pinpoint thermal stimulation was applied by moving the device vertically away from and toward the skin surface within a range of 20 mm at 10-second intervals, thereby providing repeated thermal exposure. In the TL condition, the temperature was set to 49°C; in the CL condition, the same procedure was performed with the heating function turned off.

Measurements

Cardiovascular variables

All measurements were conducted in the supine position. Participants were instructed to remain still, keep their eyes open, and avoid unnecessary movement during the experiment. HR was continuously recorded using electrocardiography (BSM-7201, Nihon Kohden Co., Tokyo, Japan). MBP was measured using an automated sphygmomanometer (BP-608, Omron Colin Co., Tokyo, Japan). Skin temperature

(SKT) was continuously monitored using a thermistor-based probe (PTC-401, Unique Medical, Osaka, Japan), which was attached adjacent to the stimulation site.

Heart rate variability

Heart rate variability (HRV) was analyzed from ECG recordings in Study 2 only. R-R intervals were extracted and visually inspected for artifacts prior to analysis. HRV analysis was performed using the Kubios HRV software (Kubios Oy, Kuopio, Finland) according to established procedures [10]. The following indices were calculated: high-frequency power in normalized units (HFnu) and the low frequency to high frequency (LF/HF) ratio. HFnu is generally considered to reflect parasympathetic activity, whereas the LF/HF ratio has been used as an index of sympathovagal balance, although these interpretations remain controversial [11–13].

Psychological indices

Immediately after each condition, participants rated their subjective responses using a numerical rating scale. Valence (0 = unpleasant, 9 = pleasant) and arousal (0 = relaxing, 9 = stimulating) were assessed [14].

Respiratory variables (subgroup analysis)

In a subset of participants ($n = 10$), respiratory rate (RR) and tidal volume (VT) were continuously recorded using a breath-by-breath gas analyzing system (ARCO2000-MET, Arcosystem, Chiba, Japan). The system was calibrated prior to each test. Respiratory variables were averaged over the same periods as cardiovascular variables. The stimulation protocol was identical to that used in Study 2.

Data processing

HR, MBP, and SKT were sampled at 200 Hz and stored on a laboratory computer system. In Study 1, values averaged over the last 60 s of the Pre period were used as baseline values, and the stimulation period was divided into three 1-min segments for analysis. In Study 2, mean values were calculated over the entire 5-min Pre and Stim periods. All data were visually inspected for artifacts, and segments with excessive noise were excluded from analysis.

Statistical analysis

All statistical analyses were performed using Jamovi (version 2.3.28.0). Data are presented as mean $\pm$ standard deviation (SD), and statistical significance was set at $p < 0.05$. In Study 1, changes over time were assessed using one-way repeated-measures analysis of variance (ANOVA). In Study 2, a two-way repeated-measures ANOVA was conducted with factors of Condition (CL vs. TL) and Time (Pre vs. Stim). The primary analysis focused on the interaction between Condition and Time. When significant main effects or interactions were observed, post hoc comparisons were performed using Bonferroni-

correction. Psychological indices (valence and arousal) were compared using paired t-test. Effect sizes were reported as partial eta squared (η_p^2) [15]. Normality of the data was assessed using the Shapiro-Wilk test.

Results

Study 1: Cardiovascular responses to continuous pinpoint thermal stimulation

The physiological responses to continuous pinpoint thermal stimulation are shown in Table 1. Figure 5a shows representative recordings of the HR response and SKT measured in one participant. A decrease in HR was observed in association with increased SKT. This effect was transient, occurring immediately after stimulation onset and gradually returning to baseline levels during continuous stimulation. A one-way repeated-measures ANOVA revealed a significant main effect of Time on HR [$F(3, 39) = 11.9, p < 0.001, \eta_p^2 = 0.478$] and SKT [$F(3,39) = 474.00, p < 0.001, \eta_p^2 = 0.973$]. Post hoc analysis revealed that HR was significantly lower during the first minute of stimulation (Stim1: $p < 0.001$) and second minute of stimulation (Stim2: $p = 0.043$) compared with Pre. These results indicate that continuous thermal stimulation induced a transient reduction in HR.

Figure 5b shows representative measurements of MBP and SKT from the same participant. MBP did not change despite the increase in SKT. A one-way repeated-measures ANOVA revealed no main effect of Time [$F(3, 39) = 2.09, p = 0.117, \eta_p^2 = 0.138$].

Table 1					
Heart rate, mean blood pressure, and skin temperature measured in continuous thermal stimulation.					
Condition	Continuous thermal stimulation				ANOVA-F values
Time	Pre	Stim1	Stim2	Stim3	Time
Heart rate (bpm)	62.8 ± 6.9	59.1 ± 6.8	60.8 ± 6.3	61.9 ± 6.7	11.9***
Mean blood pressure (mmHg)	69.8 ± 7.0	68.5 ± 6.7	71.0 ± 8.8	70.7 ± 9.3	2.09
Skin temperature (°C)	31.3 ± 1.1	41.0 ± 0.9	43.2 ± 1.0	43.4 ± 1.1	474.0***
Data are expressed as mean ± standard deviations for all subjects (n = 14). Stim1, Stim2, Stim3 are the three 1-min segments of the stimulation period. Condition: continuous thermal stimulation. Time: pre, stim. ***p < 0.001					

Study 2: Cardiac and autonomic responses to intermittent pinpoint thermal stimulation

Table 2 presents the physiological responses to intermittent pinpoint thermal stimulation for both CL and TL conditions. Figure 6 shows representative recordings of HR response and SKT for both conditions from a single participant. In the TL condition, a reduction in HR was observed in association with SKT elevation, and this effect persisted even though SKT remained constant, and was maintained until the end of thermal stimulation. In the CL condition, HR decreased slightly immediately after stimulation onset and gradually returned to baseline during stimulation. A two-way repeated-measures ANOVA (Condition $\times$ Time) revealed a significant interaction effect for HR [$F(1,14) = 16.82, p = 0.001, \eta_p^2 = 0.546$], with a significant main effect of Time [$F(1,14) = 17.92, p < 0.001, \eta_p^2 = 0.561$] but no significant main effect of Condition [$F(1,14) = 0.05, p = 0.822, \eta_p^2 = 0.004$]. Post hoc analysis showed that HR decreased significantly during the Stim period compared with the Pre period in the TL condition ($p < 0.001$). A two-way repeated-measures ANOVA (Condition $\times$ Time) also revealed a significant interaction effect for SKT [$F(1,14) = 454.00, p < 0.001, \eta_p^2 = 0.970$]. These findings indicate that bradycardic responses were sustained during intermittent thermal stimulation.

Figure 7 shows representative recordings of MBP response and SKT measured from the same participant. MBP did not change in either condition. A two-way repeated-measures ANOVA revealed no significant interaction between Condition and Time [$F(1,14) = 0.56, p = 0.465, \eta_p^2 = 0.039$] and no significant main effect of Condition [$F(1,14) = 0.08, p = 0.781, \eta_p^2 = 0.006$] or Time [$F(1,14) = 4.19, p = 0.060, \eta_p^2 = 0.230$].

Table 2 also shows the mean HFnu and LF/HF ratio. During thermal stimulation, HFnu increased, whereas LF/HF ratio decreased. A two-way repeated-measures ANOVA revealed a significant interaction between Condition and Time for HFnu [$F(1,14) = 6.97, p = 0.019, \eta_p^2 = 0.332$], but no significant main effect of Condition [$F(1,14) = 0.74, p = 0.403, \eta_p^2 = 0.050$] or Time [$F(1,14) = 0.07, p = 0.790, \eta_p^2 = 0.005$]. For the LF/HF ratio, a significant interaction was observed [$F(1,14) = 13.88, p = 0.002, \eta_p^2 = 0.498$], with no significant main effect of Condition [$F(1,14) = 2.01, p = 0.178, \eta_p^2 = 0.126$] or Time [$F(1,14) = 0.16, p = 0.698, \eta_p^2 = 0.011$]. These results suggest that intermittent thermal stimulation may enhance parasympathetic activity.

Table 2

Heart rate, mean blood pressure, skin temperature, and heart rate variability measured in thermal stimulation and control conditions

Condition	Thermal stimulation		Control		ANOVA-F values		
Time	Pre	Stim	Pre	Stim	Condition × Time	Condition	Time
Heart rate (bpm)	58.7 ± 8.7	56.0 ± 8.0	57.5 ± 9.5	56.5 ± 9.6	16.8***	0.1	17.9***
Mean blood pressure (mmHg)	75.1 ± 10.0	76.4 ± 12.3	75.1 ± 11.1	77.5 ± 12.7	0.6	0.1	4.2
Skin temperature (°C)	31.0 ± 1.3	38.8 ± 1.1	31.1 ± 0.9	30.3 ± 1.6	454.0***	608.0***	392.0***
HFnu	57.3 ± 22.5	60.2 ± 19.8	57.1 ± 25.4	52.8 ± 24.1	7.0**	0.7	0.1
LF/HF ratio	1.2 ± 1.3	1.0 ± 1.3	1.3 ± 1.7	1.6 ± 1.9	13.9**	2.0	0.2
Data are expressed as mean ± standard deviations for all subjects (n = 15). HFnu: high-frequency power in normalized units, LF/HF; low frequency/high frequency. Condition: thermal stimulation, control. Time: pre, stim. **P < 0.01, ***p < 0.001							

Psychological responses

Table 3 presents the valence and arousal scores for thermal stimulation and control conditions. A paired t-test revealed no significant difference in valence between the two conditions (p = 0.054). Similarly, no significant difference in arousal was found between conditions (p = 0.809). These findings indicate that intermittent thermal stimulation may not significantly influence subjective psychological responses.

Table 3

Psychological responses measured in thermal stimulation and control conditions

Condition	Thermal stimulation	Control	t-test p-value
Time	Stim	Stim	
Valence	5.0 ± 2.3	4.1 ± 1.6	0.054
Arousal	2.6 ± 2.7	2.5 ± 2.4	0.809

Data are expressed as mean ± standard deviations for all subjects (n = 15). Condition: thermal stimulation, control. Time: stim.

Respiratory variables

The RR and VT values are shown in Table 4. Respiratory variables showed no differences between conditions and exhibited no changes throughout the stimulation period. A two-way repeated-measures ANOVA revealed no significant interaction between Condition and Time for RR [$F(1,9) = 2.277$, $p = 0.166$, $\eta_p^2 = 0.202$], with no significant main effect of Condition [$F(1,9) = 0.695$, $p = 0.426$, $\eta_p^2 = 0.072$] or Time [$F(1,9) = 0.822$, $p = 0.388$, $\eta_p^2 = 0.084$]. For VT, no significant interaction was observed [$F(1,9) = 0.882$, $p = 0.372$, $\eta_p^2 = 0.089$], and main effects of Condition [$F(1,9) = 0.545$, $p = 0.479$, $\eta_p^2 = 0.057$] and Time [$F(1,9) = 2.971$, $p = 0.119$, $\eta_p^2 = 0.248$] were not significant. These results suggest that intermittent thermal stimulation may have little effect on respiratory variables.

Table 4
Respiratory rate and tidal volume measured in thermal stimulation and control conditions

Condition	Thermal stimulation		Control		ANOVA-F values		
Time	Pre	Stim	Pre	Stim	Condition × Time	Condition	Time
Respiratory rate (breaths/min)	16.6 ± 2.5	16.5 ± 2.2	16.8 ± 3.0	17.3 ± 2.5	2.3	0.7	0.8
Tidal volume (ml)	677.6 ± 321.9	623.5 ± 238.5	737.7 ± 530.8	657.9 ± 382.7	0.9	0.5	3.0

Data are expressed as mean ± standard deviations for all subjects analyzed ($n = 10$). Condition: thermal stimulation, control. Time: pre, stim.

Discussion

The present study examined the effects of pinpoint thermal stimulation, mimicking moxibustion, on cardiovascular responses. The main findings were as follows. First, continuous pinpoint thermal stimulation induced a reduction in HR associated with an increase in local SKT, although this response was transient and diminished as stimulation continued. Second, intermittent pinpoint thermal stimulation also reduced HR in association with increased local SKT, and this response was maintained throughout the stimulation period. Third, intermittent stimulation was accompanied by changes in HRV-derived indices associated with cardiac parasympathetic modulation. These findings indicate that the temporal pattern of thermal stimulation influences the maintenance of cardiovascular responses.

Cardiovascular responses

In both studies, pinpoint thermal stimulation induced a reduction in HR in association with an increase in local SKT. However, the temporal profile of this response differed between the two stimulation patterns. In Study 1, reduction in HR was observed during the early phase of stimulation but diminished as stimulation continued. In contrast, Study 2 demonstrated that intermittent stimulation maintained the HR reduction throughout the stimulation period. This difference indicates that the cardiovascular responses to continuous stimulation are transient, whereas intermittent stimulation is effective in maintaining the response.

One possible explanation for this difference is the temporal characteristic of afferent input evoked by thermal stimulation. Continuous stimulation likely leads to progressive attenuation of responsiveness, whereas intermittent stimulation repeatedly renews the afferent input, thereby preventing a decline in the response. In the present study, this interpretation is supported by the finding that intermittent stimulation maintained cardiovascular responses despite a lower level of sustained contact than in Study 1. Thus, not only the stimulation intensity but also the temporal pattern of stimulation appears to be important in determining the magnitude and persistence of cardiovascular effects.

Previous studies using large-area thermal stimulation, such as Waon therapy [5] and heat-and-steam generating sheets [7], have reported bradycardic responses, although these effects were generally observed during the recovery phase or were modest during stimulation. In contrast, the present study demonstrates that even highly localized thermal stimulation can induce bradycardia during the stimulation period. These findings are consistent with previous observations using indirect moxibustion [4], and suggest that pinpoint thermal stimulation reproduces, at least in part, the cardiovascular effects induced by moxibustion while differing from those induced by large-area heating.

A slight reduction in HR was also observed under non-heating conditions, suggesting that mechanical stimulation produced by contact with the device contributed, at least partially, to the observed response. Previous studies have shown that tactile stimulation—including brushing [16, 17], massage [18], and gentle cutaneous stimulation—reduces HR. Taken together, the present findings suggest that both thermal and mechanical inputs are involved in the cardiovascular responses during pinpoint stimulation.

MBP did not change in either study. Blood pressure is determined by multiple factors, including cardiac output and peripheral vascular resistance [19]. The present stimulation therefore appears to be sufficient to alter HR, but not strong enough to produce measurable changes in broader determinants of blood pressure.

Autonomic responses and physiological considerations

In Study 2, intermittent pinpoint thermal stimulation was associated with an increase in HFnu and a decrease in LF/HF ratio, accompanied by sustained bradycardia. Previous studies have also reported that thermal stimulation alters HRV-related indices [4–7]. Accordingly, the present findings support the interpretation that autonomic modulation contributes to the sustained cardiovascular response observed during intermittent stimulation.

However, these results should be interpreted with caution. HRV-derived indices provide only indirect estimates of autonomic activity and are influenced by multiple factors, including respiration. In the present study, respiratory variables did not change under similar experimental conditions, suggesting minimal contribution of respiration. Nonetheless, HRV alone does not provide direct evidence of sympathetic or parasympathetic neural activity. Thus, while the present results support the involvement of autonomic modulation, they do not identify the precise underlying neural mechanism.

Previous studies have shown that acupuncture and moxibustion modulate cardiovascular responses through afferent neural pathways [20–25]. These responses are considered to involve coordinated changes in sympathetic and parasympathetic activity [26]. The present findings are consistent with this framework, because intermittent stimulation altered HRV-derived indices while maintaining HR reduction. However, in the absence of direct evidence for sympathetic modulation, further investigation is required to clarify how these responses are generated.

Localized thermal stimulation is detected by thermosensitive receptors, including transient receptor potential (TRP) channels. Among these, transient receptor potential vanilloid type-1 (TRPV1) is activated by heat and mechanical stimulation and has been implicated in local vascular and neural responses [8, 27, 28]. In the present study, SKT reached levels sufficient to activate thermosensitive pathways, indicating the involvement of such mechanisms in the observed responses. TRPV1 is expressed in A δ and C afferent fibers and has been linked to cardiovascular responses induced by acupuncture and moxibustion [23, 25, 29–31]. These afferent signals are transmitted to central autonomic regulatory regions and influence cardiovascular function [24]. Other thermosensitive channels such as TRPV3 and TRPV4 are also involved in thermal perception [28, 32, 33]. The present findings therefore suggest that localized thermal stimulation activates thermosensitive afferent pathways that contributes to the observed cardiovascular responses, although the specific receptors involved were not investigated.

Clinical implications

The present findings have several clinical implications. First, pinpoint thermal stimulation induces cardiovascular responses without adverse events, despite local increases in skin temperature. Previous studies have shown that thermal pain thresholds depend on both stimulus temperature and stimulation area [34–36]. The small stimulation area used in the present study likely reduced the overall sensory burden compared with large-area heating. Second, intermittent stimulation maintained SKT at a moderate level and did not induce marked discomfort, suggesting that intermittent pinpoint stimulation is more suitable for repeated application than continuous contact stimulation. In addition, the sustained reduction in HR observed during intermittent stimulation indicates that this approach may have potential as a non-pharmacological adjunct for cardiovascular regulation.

Pharmacological approaches, such as β -blockers and ivabradine, are widely used to reduce HR [37–42]. These agents are effective, but their use may be limited by contraindications or adverse effects. The present findings do not support a direct clinical substitute for these agents; however, they do indicate that pinpoint thermal stimulation has potential as a complementary, non-invasive approach.

Control of HR is also important in cardiovascular imaging such as computed tomography, because lower HR improves image quality [43–45]. The HR reduction observed in the present study therefore has possible clinical relevance. However, the magnitude, reliability, and clinical utility of this effect remain to be determined.

Limitations

Several limitations should be acknowledged. First, the sample size was relatively small, and the participants were limited to healthy young individuals. Accordingly, the generalizability of the present findings to other populations, including older adults and patients with cardiovascular disease, remains unclear. Second, menstrual cycle phases were not controlled in female participants, although autonomic activity is known to vary across the menstrual cycle [46, 47]. This factor may have contributed to inter-individual variability in the responses. Third, autonomic activity was assessed using HRV-derived indices. Although these indices are useful for evaluating autonomic modulation, they do not provide a direct measure of autonomic outflow. In addition, although respiratory variables did not change under similar experimental conditions, the influence of respiration cannot be completely excluded [48]. Fourth, a slight reduction in SKT was observed under non-heating conditions. This finding may reflect environmental influences, such as ambient temperature, exposure of the stimulation site, or heat transfer associated with device contact. These factors may have affected the baseline thermal condition. Finally, the present study focused on short-term responses to pinpoint thermal stimulation. The effects of repeated application over a longer period were not examined. Future studies should therefore include larger and more diverse populations, investigate extended or repeated stimulation, and incorporate additional physiological measurements to clarify the mechanisms underlying the observed responses and assess their clinical applicability.

Conclusion

In conclusion, pinpoint thermal stimulation, mimicking moxibustion, reduced HR in association with an increase in local SKT. This response was transient during continuous stimulation but was maintained during intermittent stimulation. These findings indicate that the temporal pattern of stimulation is an important determinant of sustained cardiovascular effects. Intermittent pinpoint thermal stimulation represents a non-invasive approach for sustaining HR reduction without altering blood pressure. The present findings provide a physiological basis for the effects of localized thermal stimulation and contribute to understanding its potential role in cardiovascular regulation.

Abbreviations

CL	
Control condition	
TL	
Thermal stimulation condition	
HFnu	

High-frequency power in normalized units

HR

Heart rate

HRV

Heart rate variability

LF/HF

Low frequency/high frequency

MBP

Mean blood pressure

RR

Respiratory rate

VT

Tidal volume

SKT

Skin temperature

TRP

Transient receptor potential

TRPV1

transient receptor potential vanilloid type-1

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Declarations

Ethics approval and consent to participate

All protocols were reviewed and approved by the Ethics Committee of Morinomiya University of Medical Sciences (approval no. 2019-057) and were conducted in accordance with the principle of the Declaration of Helsinki. Written Informed consent was received from all participants after they were given full explanations of the objectives, methods, and potential risks of the study.

Clinical trial number

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Funding

The study was supported by internal funding from Morinomiya University of Medical Sciences.

Author Contribution

KI and HN conceived and designed the study. KI conducted experiments. KI and HN analyzed the data. KI wrote the manuscript. HN reviewed the manuscript. Both authors read and approved the final manuscript.

Acknowledgements

Not applicable.

Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding authors upon reasonable request.

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Figures

Figure 1

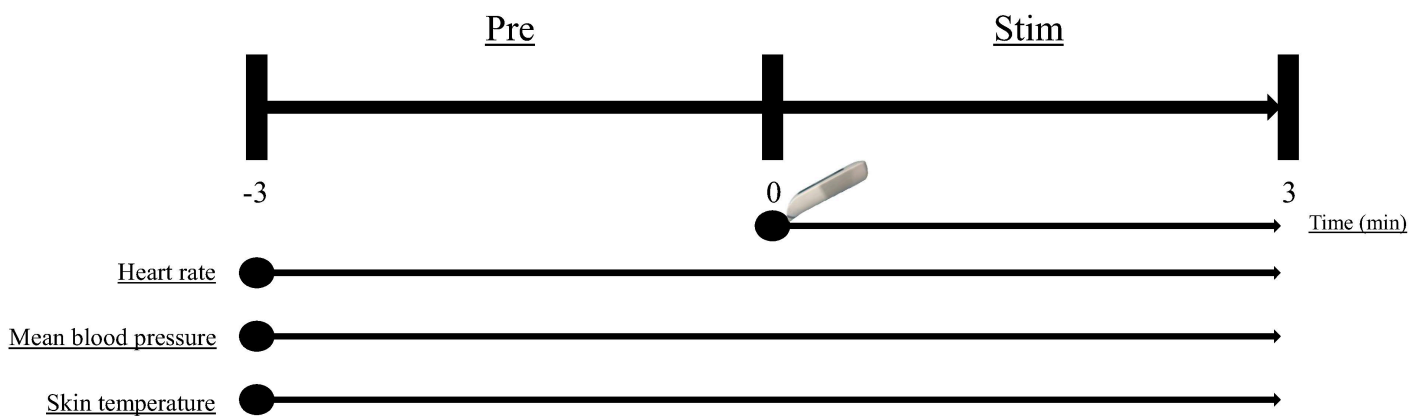


Figure 1

Protocol of the exploratory experiment in Study 1.

Figure 2

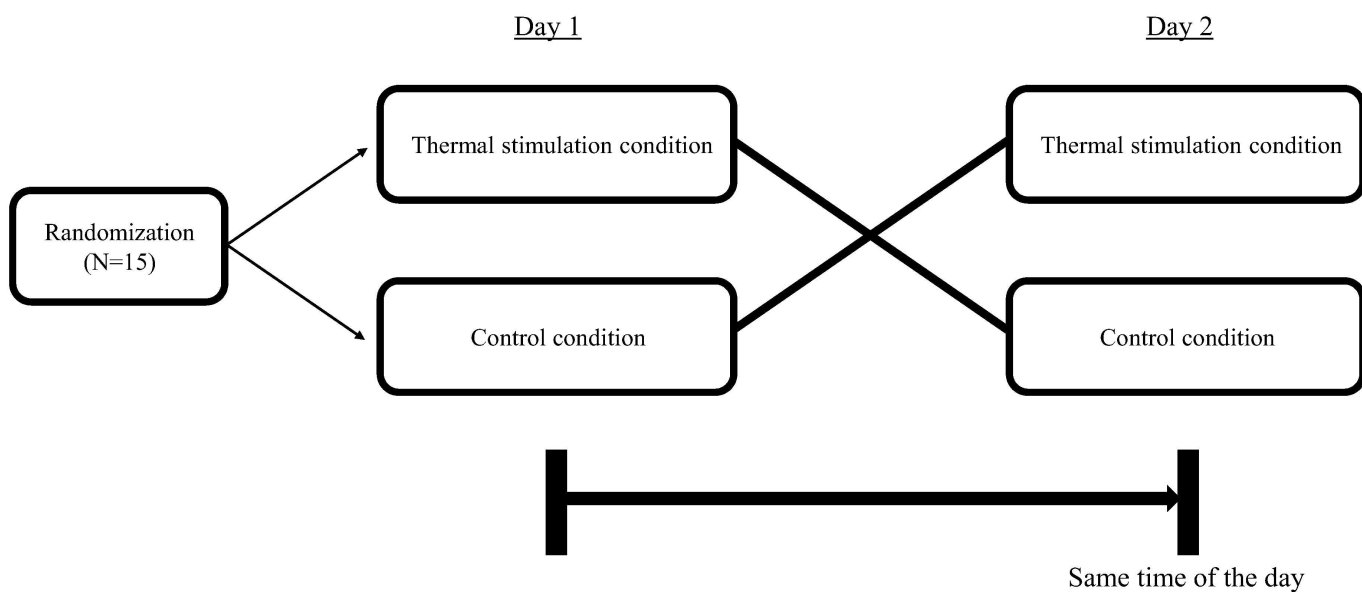


Figure 2

Study 2: a randomized crossover trial with a control condition and a thermal stimulation condition.

Figure 3

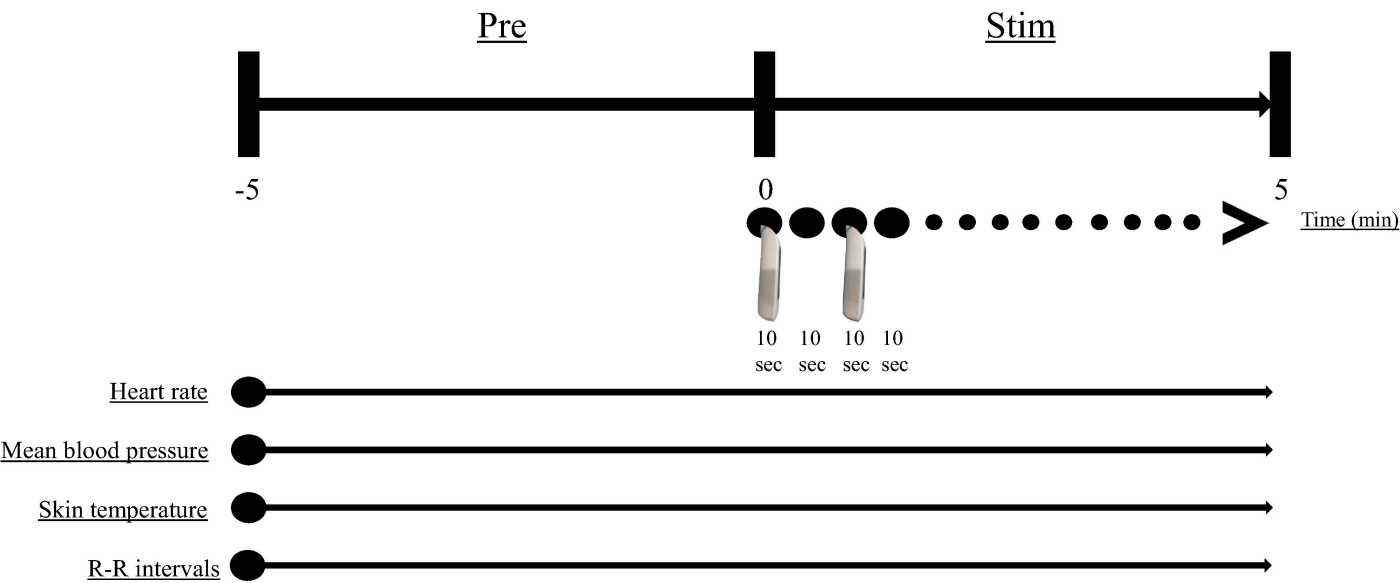


Figure 3

Protocol of the controlled experiment in Study 2.

Figure 4



Figure 4

Electronic moxibustion device.

Figure 5

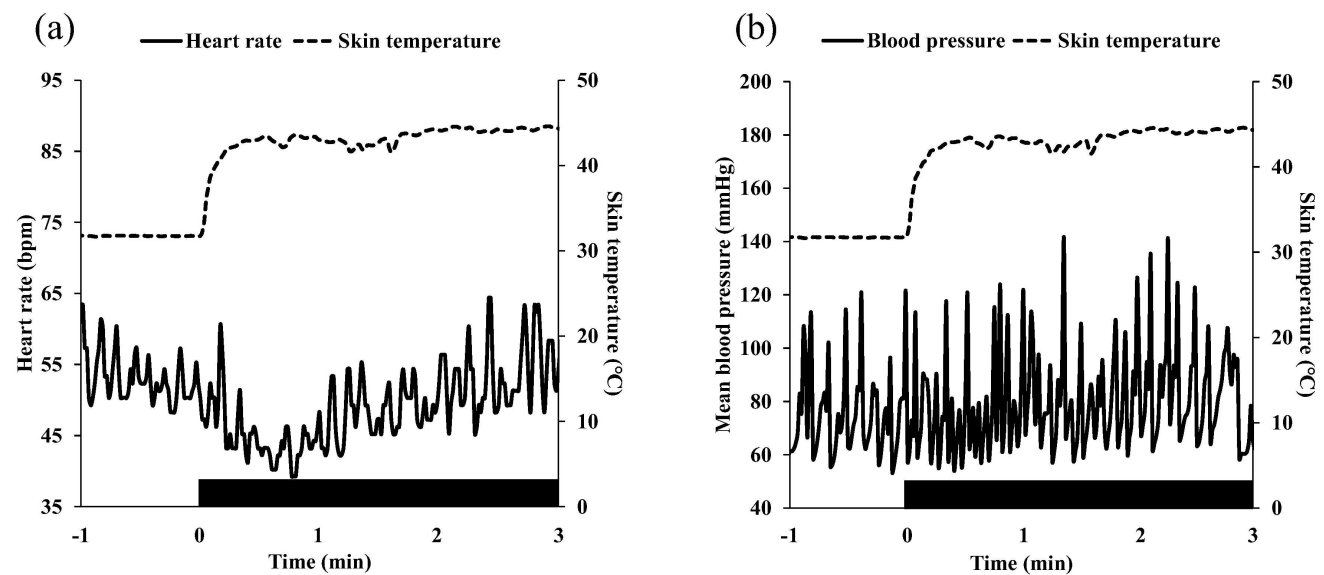


Figure 5

Representative recordings of heart rate (a) and mean blood pressure responses (b) in the same participant. The solid line represents heart rate or mean blood pressure, and the dotted line represents skin temperature. Black horizontal bar denotes the stimulation period.

Figure 6

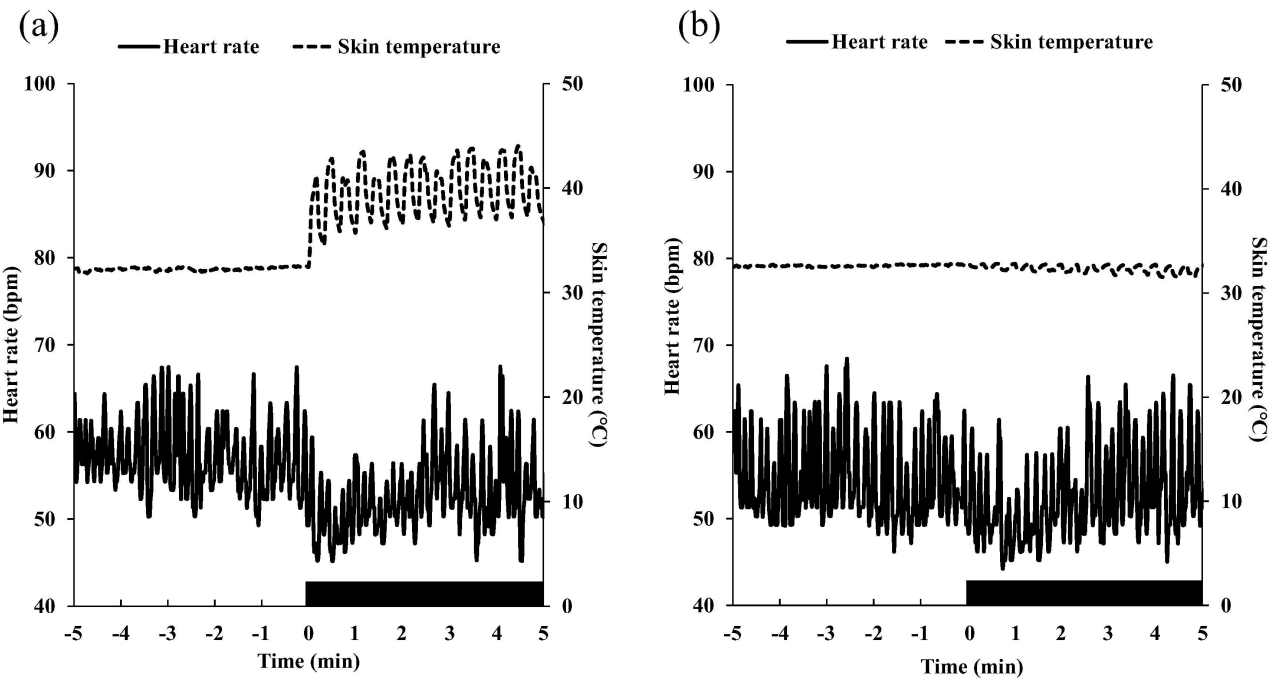


Figure 6

Representative recordings of heart rate and skin temperature in the single participant. Heart rate and skin temperature measured under the thermal stimulation (a) and control (b) conditions. The solid line represents heart rate, and the dotted line represents skin temperature. Black horizontal bar denotes the intervention period.

Figure 7

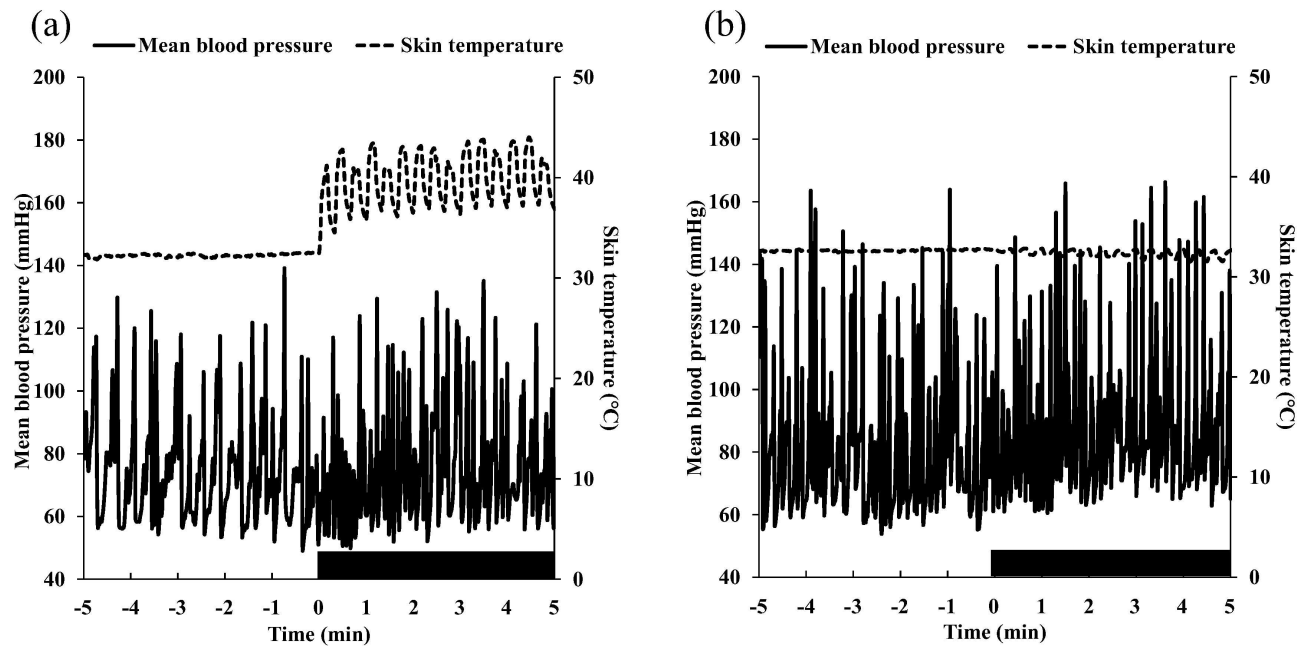


Figure 7

Representative recordings of mean blood pressure and skin temperature in the single participant.

Mean blood pressure and skin temperature measured under thermal stimulation (a) and control (b) conditions. The solid line represents mean blood pressure, and the dotted line skin temperature. Black bar denotes the intervention period. The same participants as those shown in Figure 6.