Original research paper

Modulation of radial blood flow during Braille character discrimination task

Running title: Change in blood flow during Braille reading

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Abstract

Purpose: Human hands are excellent in performing sensory and motor function. We hypothesized that blood flow of the hand are dynamically regulated by sympathetic outflow during concentrated finger perception. To identify this hypothesis, we measured radial blood flow (RBF), radial vascular conductance (RVC), heart rate (HR), and arterial blood pressure (AP) during Braille reading performed under the blind condition in nine healthy subjects. The subjects were instructed to read a flat plate with raised letters (Braille reading) for 30 s by the forefinger, and to touch a blank plate as control for the Braille discrimination procedure.

Results: HR and AP slightly increased during Braille reading but remained unchanged during the touching of the blank plate. RBF and RVC were reduced during the Braille character discrimination task (decreased by -46% and -49%, respectively). Furthermore, the changes in RBF and RVC were much greater during the Braille character discrimination task than during the touching of the blank plate (decreased by -20% and -20%, respectively).

Conclusions: These results suggested that the distribution of blood flow to the hand is modulated via sympathetic nerve activity during concentrated finger perception.

Keywords: Radial blood flow; Discrimination task; Sympathetic nerve activity; Healthy human

Introduction

Human hands are excellent in performing sensory and motor function. For example, humans are able to discriminate the texture, shape, and temperature against the finger surface. Glabrous skin of the fingers is deformed when touching an object. This deformation produces excitation of the tactile units innervating the glabrous skin of the fingers, which can be transmitted to the central nervous system. When Johansson et al. (5, 6) studied the receptive field and response patterns of the mechanoreceptive units using microneurography in humans, they showed that mechanoreceptive units were abundant at the fingertip and characterized as a rapidly or slowly adapting fiber, which contributed to perception of a mechanical event on the skin surface.

On the other hand, it is well known that the glabrous skin of the hand contains rich arteriovenous anastomoses (AVA), which are densely innervated by sympathetic vasoconstrictor fibers (8, 9, 19). The vasoconstrictor system plays a role in reflex adjustments to thermal and exercise challenges (1, 7, 8, 11, 17, 18, 21, 22). Since Macefield and Elam (3, 12) reported that firing of tactile afferents in the human finger pads had a relationship with arterial pulsation occurring within the finger, it is likely that regulation of blood flow to the fingers plays an important role in not only thermoregulatory modulation but also the aforementioned sensory mechanism. However, the close relationship between finger circulation and perception remained unknown.

The aim of this study was to test the hypothesis that the blood flow of the hand is controlled by sympathetic outflow during concentrated finger perception. To examine this, we measured radial blood flow using an ultrasound Doppler system during a Braille character discrimination task performed under blind conditions in healthy humans.

Methods

Subjects

Nine male subjects participated in this study: age 23.9 ± 0.7 (mean ± standard error of the mean; SEM) yr, height: 171.4 ± 1.7 cm, and weight: 67.3 ± 1.3 kg. All subjects, who were right-handed, were healthy and had not taken any medication. The experimental procedures were informed to them in advance, and their written consents were obtained. This study was performed in accordance with the Declaration of Helsinki and approved by the Institutional Ethical Committee of Hiroshima University.

Measurements

A pair of electrodes (Magnerode, TE-18M-3, Fukuda Denshi, Tokyo, Japan) was attached on the subject's chest for electrocardiogram (ECG) measurement. The ECG signal and respiratory movement were monitored with a telemetry system (DynaScope DS-3140, Fukuda Denshi, Tokyo, Japan). A blood pressure cuff was attached to the middle finger of the left hand for noninvasively and continuously monitoring arterial blood pressure (AP) with a Finometer (Finapres Medical Systems BV, Arnhem, the Netherlands). Radial blood flow velocity (VEL; cm/s) and two-dimensional images (B-mode image) of the radial artery were measured using the Doppler ultrasound system (Vivid 7, GE Marquette Medical Systems, Tokyo, Japan). The Doppler probe (7.5-MHz linear array transducer) was adjusted manually over the radial artery by one of the investigators. Mean vessel internal diameter (Dm) was calculated as systolic internal diameter/3 + diastolic internal diameter×2/3, as previously reported (4, 10). Radial blood flow (RBF; ml/min) was calculated every beat as the product of mean VEL and vessel cross sectional area ($\pi Dm^2/4$) multiplied by the corresponding heart rate (HR). Radial vascular conductance (RVC) was taken as RBF divided by mean AP (MAP).

ECG, AP, and the marking signal were simultaneously stored on a computer using an analogue-digital converter (MP100, BIOPAC systems; Santa Barbara, CA, USA) at a sampling frequency of 1 kHz. The beat-to-beat HR, systolic AP (SAP), and diastolic AP (DAP) data were stored on a hard disk for off-line analysis using a software program (AcqKnowledge 3.7.3; BIOPAC systems; Santa Barbara, CA, USA). The VEL data, two-dimensional images of the radial artery, and keyboard signals were stored by a videotape recorder. The timing of the start and end of the task were manually marked using an electric switch and the keyboard switch of the Doppler ultrasound system.

Braille character discrimination task

We made flat plates with raised letters as shown in Figure 1. The convexities (diameter: 3 mm, height: 1 mm) on the plates were arranged according to Braille code. Two flat plates were located at 2 cm intervals on the back face of a desk so as to simulate blind conditions. The subjects were instructed to start touching one of the flat plates upon receiving our cue.

Procedures

All experiments were performed in a sound-proof room at an ambient temperature of 22-24°C and a relative humidity of 50%. After all preparations were finished, each subject was allowed to sit on a chair for more than 10 min to stabilize their cardiovascular variables. The experiments consisted of two procedures. First, each subject was asked to touch two flat plates with raised letters for 30 s (left plate 15 s, right plate 15 s) using the right index finger. After a rest for 30 s, each one was asked to answer the Braille character that they touched by consulting a Braille chart. Second, each subject was asked to touch two flat plates without any raised letters for 30 s (left plate 15 s, right plate 15 s) as control. We informed in advance that the flat plate did not have any raised letters and instructed everyone to move their index finger in the same manner as for the Braille discrimination procedure. The above two procedures were performed in a random order. In 6 of the 9 subjects, to examine the effect of concentrated finger perception task on the blood flow of the contralateral hand, RBF at the left side was measured during Braille discrimination task, which was performed using the right hand.

Data analysis

The beat-to-beat measurements of HR, MAP, Dm, VEL, RBF, and RVC were averaged every 2 sec. The mean values of these parameters obtained for 30 s before the touching of the flat plates were defined as the baseline levels. The value at the baseline in each procedure was statistically compared with the mean value obtained during the touching of the flat plates using a paired-*t* test. The changes in RBF and RVC are expressed as percentage changes from the baseline levels. In each procedure, the changes in HR(beats/min), MAP(mmHg), RBF (%), and RVC (%) from the baseline levels for an individual subject were aligned at the onset of the flat plate touching and were further averaged among subjects. These data were statistically compared between the touching the blank plate and Braille reading conditions using two-way analysis of variance (ANOVA). Furthermore, the mean values of the changes in HR, MAP, RBF, and RVC detected during the flat plate touching were statistically analyzed by one-way ANOVA among the three procedures (touching the blank plate, the ipsilateral responses to Braille reading, and the contralateral responses to Braille reading). When a significant *F*-value was present for a main effect, a Tukey *post hoc* test was performed to detect significant differences from the mean value. The level of statistical significance was defined as $P < 0.05$. The data are expressed as the mean ± SEM.

Results

Cardiovascular responses to touching a blank plate or reading a Braille character

The mean baseline HR, MAP, Dm, VEL, RBF, and RVC values and those obtained during the touching of a blank plate or the reading of a Braille character are summarized in Table 1. During the Braille reading, HR and MAP displayed mean increases from their baseline values of 4.3±1.9 beats/min (P<0.05) and 7.3±1.0 mmHg (P<0.05), respectively. However, HR and MAP were unchanged during the touching of the blank plate. The internal diameter of the radial artery did not change during the touching of the blank plate or the Braille reading. On the other hand, VEL, RBF, and RVC decreased during the Braille reading. The mean decreases in VEL, RBF, and RVC during the Braille reading were 14.0±1.9 cm/s (decreased by -48.7±6.7%, P<0.05), 49.2±7.6 ml/min (decreased by -46.2±6.5%, P<0.05), and 0.6±0.07 ml/min/mmHg (decreased by -48.7±6.6 %, P<0.05), respectively. Similarly, VEL, RBF, and RVC were reduced during the touching of the blank plate. The mean decreases in VEL, RBF, and RVC during the touching of the blank plate were 5.0±1.3 cm/s (decreased by -16.7±4.4%, P<0.05), 22.2±4.6 ml/min (decreased by -19.6±4.0%, P<0.05), and 0.3±0.04 ml/min/mmHg (decreased by -19.6±3.9%, P<0.05), respectively. However, the changes in VEL, RBF, and RVC observed during the Braille reading were much greater than those seen during the touching of the blank plate.

In a comparison between the responses of the ipsilateral and contralateral hands to Braille reading, we found that the VEL and RBF of the contralateral hand decreased by 5.4±3.7 cm/s (decreased by -18.5±8.5%, P<0.05) and 21.1±8.5 ml/min (decreased by -23.7±7.9%, P<0.05), respectively. On the other hand, the change in HR was 2.5±0.5 beats/min (P<0.05). The contralateral responses of VEL and RBF were much smaller than their ipsilateral responses, whereas the HR response was not significantly different between the two experimental groups.

Time course of the changes in HR, MAP, RBF, and RVC during the touching of a blank plate or Braille reading

The time courses of the changes in HR, MAP, RBF, and RVC before, during, and after the touching of the blank plate and Braille reading are shown in Fig. 2. HR and MAP slightly increased during Braille reading but remained unchanged during the touching of the blank plate ($P < 0.05$). On the other hand, RBF remarkably decreased during Braille reading. The decrease in RBF reached a maximum value of -55.2±8.3% at 14s after the onset of Braille reading, which was maintained during the later period of Braille reading. RBF returned slowly to the baseline level after the cessation of Braille reading. RBF was also decreased during the touching of the blank plate (decreased by -33.5±9.2%). However, this response in RBF was much smaller than the response to Braille reading ($P < 0.05$). The changes in RVC followed the changes in RBF because the change in MAP was small.

Discussion

To identify whether the blood flow of the hand is sympathetically modulated during concentrated finger perception, we measured the blood flow and vascular conductance of the radial artery during a Braille character discrimination task performed under blind conditions in healthy humans. Our new major finding is that RBF was reduced during the Braille character discrimination task. The change in RVC followed the response in RBF because the change in arterial blood pressure was small. Furthermore, the changes in RBF and RVC were much greater during the Braille character discrimination task than during the touching of the blank plate. If the reflex caused by finger movement was important, the responses in RBF and RVC should be the same between the touching of the plate containing a raised letter and the touching of the blank plate. These results suggested that the distribution of blood flow to the hand is modulated by concentrated finger perception.

One limitation of our study is that the subjects had been told in advance that they would be touching a flat plate. Thus, it was considered that this method encouraged the subjects to anticipate a pattern. Moreover, this anticipation might have augmented feed-forward cardiovascular regulation, termed central command, which represents descending signals arising from higher brain centers (15). Central command is likely to cause sympathoexcitation, which contributes to the rapid cardiovascular adaptation observed during exercise (16, 20). The responses in HR, AP, and blood flow of the hand to Braille reading observed in this study might have been strongly affected by central command. Another limitation of our study is related to the measurement of the contralateral response to the task. In this study, it was difficult to measure RBF and AP simultaneously in the same arm. Thus, we did not assess the change in RVC induced in the contralateral hand in response to the Braille reading task. Moreover, the contralateral RBF response was only recorded during Braille reading. Therefore, the differences between ipsilateral and contralateral blood flow during concentrated finger perception remain obscure. Further studies are required to investigate these points.

In this study, no change in the internal diameter of the radial artery was detected during Braille reading. However, its flow velocity and volume flow decreased during the Braille task. These findings suggest that the stimulation of adrenergic sympathetic outflow during the task caused vasoconstriction in the small arterial vessels of the hand, followed by a decrease in the flow velocity and volume flow of the upstream large artery (radial artery). It is well known that the hand is highly vascularized (2). In particular, the glabrous skin areas of the hand are rich in AVA, which causes large fluctuations in skin blood flow in these areas. Moreover, the glabrous skin is innervated by sympathetic adrenergic vasoconstrictor nerves, but lacks influence from active vasodilator nerves (8, 9). Previous studies reported that sympathetically-mediated vasoconstriction is evoked in the glabrous skin during cold stress (8, 14) and dynamic or isometric exercise (11, 18, 22). This sympathetically-mediated vasoconstriction in the hand might also be evoked by concentrated finger perception tasks, which in turn contributes to reducing the flow velocity and volume flow of the radial artery.

On the other hand, skin blood flow of the hand is influenced by mental stress such as mental arithmetic (13). However, the decrease in RBF observed during a Braille character discrimination task would not been simply influenced by mental stress. The discrimination task used in this study caused little mental stress, because the changes in HR and MAP were negligible. Moreover, the change in RBF observed during the discrimination task was greater on the ipsilateral side than on the contralateral side. If blood flow to the hand is reduced by mental stress due to the discrimination task, the same change in RBF should be observed on both sides. This regional difference in the radial blood flow response to the task might have been caused by central modulation of the sympathetic nervous system in order to evoke fine tactile discrimination.

The decrease in blood flow in the hand during the Braille discrimination task may influence finger blood volume. We have considered a new hypothesis for the physiological function of the reduction of blood volume via sympathetic control during concentrated finger perception. The hypothesis is that a decrease in blood volume may induce a decrease in skin surface pressure, which in turn results in the deformation of the cutaneous tissues. Previous studies reported that the background firing rate of tactile afferents arising from mechanoreceptive units in the finger pads was related to arterial pulsations (3, 12). Furthermore, the background firing rate of slowly adapting afferents was also reduced by a decrease in finger blood flow corresponding to the inspiratory phase (12). Taken together, by changing the mechano-elastic characteristics of the cutaneous tissue at the fingertip, a decrease in radial blood flow may contribute to augmenting the tactile sensitivity.

In conclusion, the present study suggests that blood flow to the hand is dynamically modulated via sympathetic nerve activity during a tactile discrimination task. The sympathetic vasoconstrictor system may play a role in the regulation of the sensory function of the hand.

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References

1. Bini G, et al.: Regional similarities and differences in thermoregulatory vaso- and sudomotor tone. J Physiol. 306, 553-565 (1980)

2. Chaudakshetrin P, et al.: The arteriovenous pattern of the distal digital segment. J Hand Surg [Br]. 13, 164-166 (1988)

3. Elam M, Macefield VG: Does sympathetic nerve discharge affect the firing of myelinated cutaneous afferents in humans? Auton Neurosci. 111, 116-126 (2004)

4. Ichinose M, Nishiyasu T: Muscle metaboreflex modulates the arterial baroreflex dynamic effects on peripheral vascular conductance in humans. Am J Physiol Heart Circ Physiol. 288, H1532-H1538 (2005)

5. Johansson RS: Tactile sensibility in the human hand: receptive field characteristics of mechanoreceptive units in the glabrous skin area. J Physiol. 281, 101-125 (1978)

6. Johansson RS, Vallbo AB: Tactile sensibility in the human hand: relative and absolute densities of four types of mechanoreceptive units in glabrous skin. J Physiol. 286, 283-300 (1979)

7. Johnson JM: Nonthermoregulatory control of human skin blood flow. J Appl Physiol. 61, 1613–1622 (1986)

8. Johnson JM, et al.: Skin of the dorsal aspect of human hands and fingers possesses an active vasodilator system. J Appl Physiol. 78, 948-954 (1995)

9. Kellogg DL Jr: In vivo mechanisms of cutaneous vasodilation and vasoconstriction in humans during thermoregulatory challenges. J Appl Physiol. 100, 1709-1718 (2006)

10. Kitano A, et al.: Comparison of cardiovascular responses between lower body negative pressure and head-up tilt. J Appl Physiol. 98, 2081-2086 (2005)

11. Kondo N, et al.: Effects of muscle metaboreceptor stimulation on cutaneous blood flow from glabrous and nonglabrous skin in mildly heated humans. J Appl Physiol. 94, 1829-1835 (2003)

12. Macefield VG: Cardiovascular and respiratory modulation of tactile afferents in the human finger pad. Exp Physiol. 88, 617-625 (2003)

13. Marriott I, et al.: Cutaneous vascular responses evoked in the hand by the cold pressor test and by mental arithmetic. Clin Sci (Lond). 79, 43-50 (1990)

14. Marshall JM, et al.: Analysis of vascular responses evoked in the cutaneous circulation of one hand by cooling the contralateral hand. J Auton Nerv Syst. 31, 57-66 (1990)

15. Mitchell JH. Neural control of the circulation during exercise. Med Sci Sports Exer. 22, 141-154 (1990)

16. Murata J, et al.: Central inhibition of the aortic baroreceptors-heart rate reflex at the onset of spontaneous muscle contraction. J Appl Physiol. 97, 1371-1378 (2004)

17. Rowell LB: Reflex control of the cutaneous vasculature. J Invest Dermatol. 69, 154–166 (1977)

18. Saad AR, et al.: Influence of isometric exercise on blood flow and sweating in glabrous and nonglabrous human skin. J Appl Physiol. 91, 2487-2492 (2001)

19. Sherman JL: Normal arteriovenous anastomoses. Medicine 42, 247–267 (1963)

20. Tsuchimochi H, et al.: Direct measurement of cardiac sympathetic efferent nerve activity during dynamic exercise. Am J Physiol Heart Circ Physiol. 283, H1896-H1906 (2002)

21. Vissing SF, et al.: Stimulation of skin sympathetic nerve discharge by central command. Circ Res. 69, 228-238 (1991)

22. Yamazaki F: Vasomotor responses in glabrous and nonglabrous skin during sinusoidal exercise. Med Sci Sports Exerc. 34, 767-772 (2002)

Table 1. Comparison of the mean baseline HR, MAP, Dm, VEL, RBF, and RVC values with those observed during the touching of a blank plate or Braille reading

	Braille reading (ipsilateral) n=9		Braille reading (contralateral) n=6		Touching a blank plate (ipsilateral) n=9	
	Before	During	Before	During	Before	During
HR, beats/min	65.0±3.0	68.8±3.3 *†	66.2±4.0	68.7±4.1 *	64.5±2.6	62.1±2.5
MAP, mmHg	85.1±3.2	92.4±3.5 *†	——	——	84.3±3.5	84.3±3.4
Dm, cm	0.27±0.01	0.27±0.01	0.28±0.01	0.28±0.01	0.27±0.01	0.27±0.01
VEL, cm/s	30.1±2.4	16.1±3.3 *†‡	27.7±1.7	22.3±3.3 *	32.0±2.4	27.0±3.0*
RBF, ml/min	111.0±10.5	61.8±12.1*†‡	113.4±6.9	92.3±12.6*	117.8±9.5	95.6±10.4*
RVC, ml/min/mmHg	1.35±0.16	0.74±0.18 *†	——	——	1.43±0.15	1.17±0.16*

Values are shown as the mean ± SEM. HR, heart rate; MAP, mean arterial pressure; Dm, internal diameter; VEL, radial blood flow velocity; RBF, radial blood flow; RVC, vascular conductance. * Significantly different from the baseline value, $P < 0.05$. † Significantly different from the value obtained during the touching of a blank plate, $P < 0.05$. ‡ Significantly different from the value observed in the contralateral hand during Braille reading, $P < 0.05$.

Figure legends

Figure 1

Braille character discrimination task. The convexities (diameter: 3 mm, height: 1 mm) on the plate were arranged according to Braille code. Two flat plates were located at 2 cm intervals.

Figure 2

Time course of mean changes (Δ) in HR, MAP, RBF, and RVC before, during, and after the touching of a blank plate (○) or Braille reading (●). The duration of the plate touching is shown by the horizontal bar. Values are mean ± SEM. Significant difference between the touching of the blank plate and Braille reading: *$P < 0.05$.

Figure 1

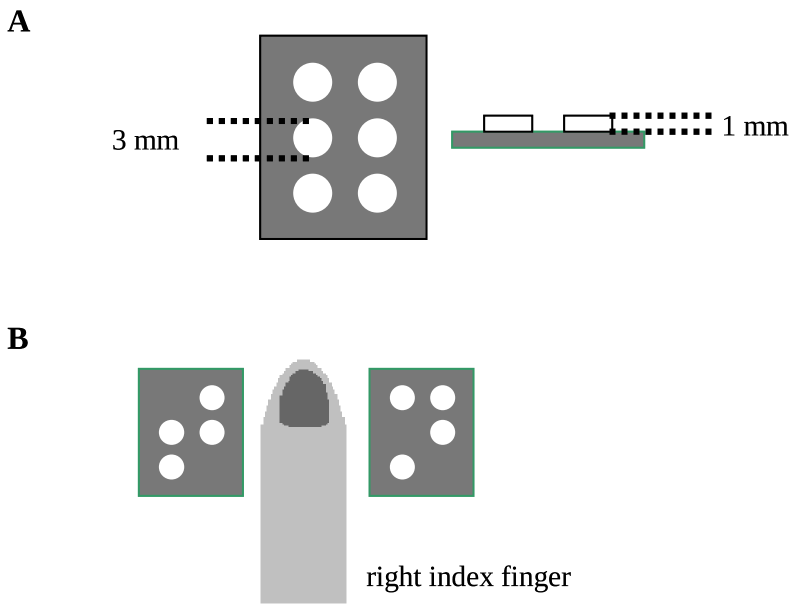
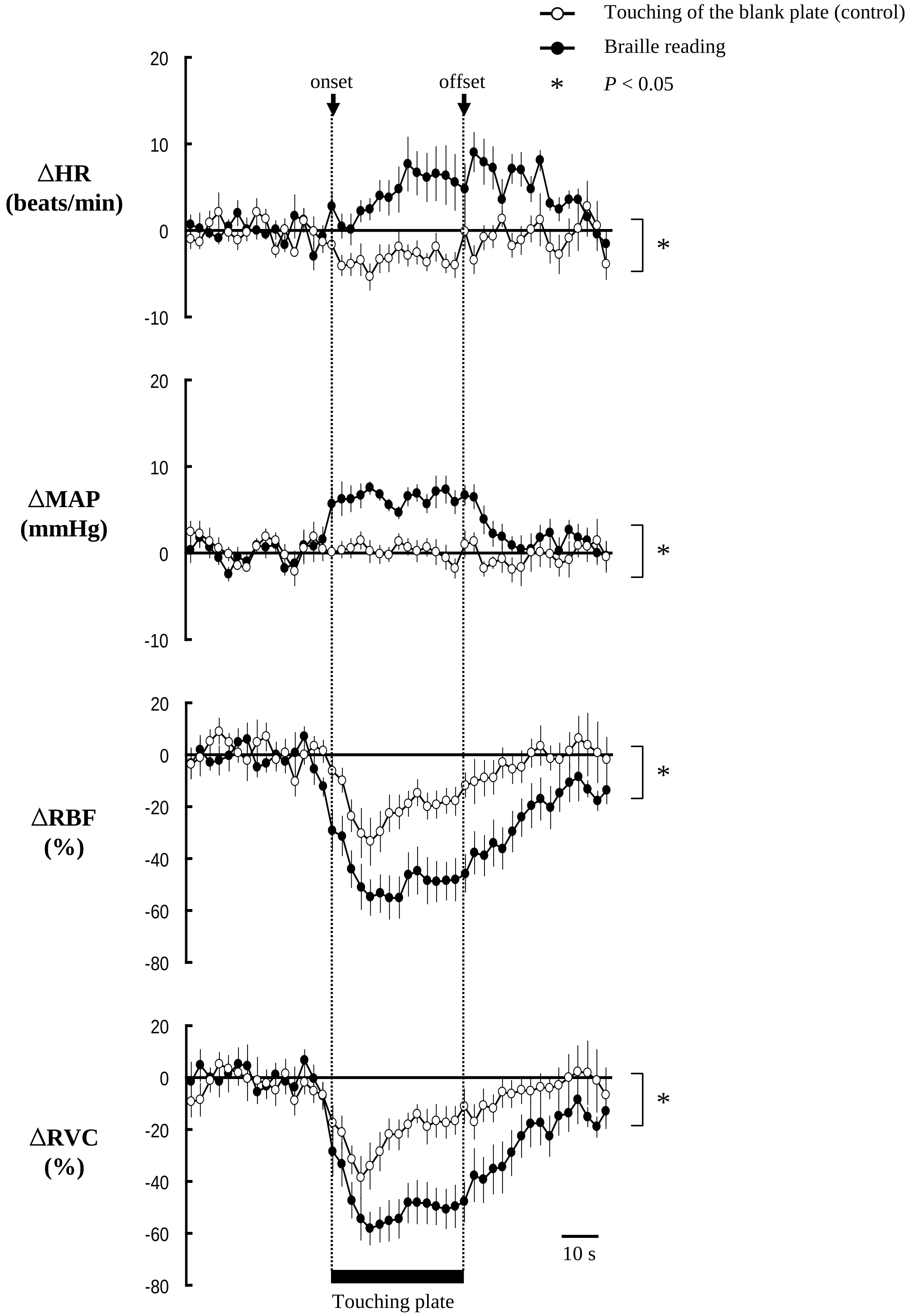


Figure 2


Touching of the blank plate (control)
Braille reading
* P < 0.05
onset
offset
ΔHR (beats/min)
ΔMAP (mmHg)
ΔRBF (%)
ΔRVC (%)
20
10
0
-10
-20
-40
-60
-80
*
10 s
Touching plate