International Journal of Affective Engineering
J-STAGE Advance Published Date: 2024.05.02
doi: 10.5057/ijae.IJAE-D-23-00008

Letter

Vibratory Stimuli to the Thoracoabdominal Region Elicit Stronger Fear Responses than Those to the Fingers

Tatsuki MAKIOKA[1] and Shogo OKAMOTO[1*†]

[1] Tokyo Metropolitan University, 6-6 Asahigaoka, Hino-shi, Tokyo 191-0065, Japan

[*] Corresponding author, E-mail: okamotos@tmu.ac.jp
[†] JSKE Member

Received: 2023.04.12
Accepted: 2024.03.21

Abstract: Mechanical vibratory stimuli applied to the thoracoabdominal region enhance emotional experiences while watching movies. We hypothesized that these vibrations to the thoracoabdominal region stimulate the vagus nerves, which are distributed in the upper body organs, causing interoceptive sensations that influence emotions. To investigate this hypothesis, we compared the effects of vibratory stimuli on fear between the thoracoabdominal region and fingers, which have the highest tactile sensitivity in the body, while watching horror movies. The results showed that vibratory stimuli to the thoracoabdominal evoked greater subjective evaluations than those to the fingers and conditions without vibratory stimuli. Further, greater skin conductance responses were caused by the stimulation to the thoracoabdominal region than the no vibratory condition. These findings suggest that mechanical vibratory stimuli to the vagus nerve play a crucial role in shaping emotional experiences.

Keywords: Interoceptive stimuli, Emotion, Vagus nerve, Vibration, Fear

1. Introduction

Vibratory stimuli to the upper body while watching audiovisual content magnify the emotional experience evoked by the content (Karafotias et al., 2017; Branje et al., 2014). In these studies, vibratory stimuli were mainly presented to the thoracoabdominal region, and their emotional impacts were confirmed by subjective evaluation and physiological responses. Although the underlying principle of how vibratory stimuli influence emotions has yet to be clarified, a promising hypothesis is that mechanical vibratory stimuli, including vibration and pressure, induce visceral or interoceptive sensations pertaining to emotions (Sakurai et al., 2014; Damasio, 2003). The vagus nerve has been considered as a potential mediator in this process, as it is responsible for monitoring and controlling visceral activities. Mechanical stimulation to body segments, such as the outer ear, cause physiological changes (Addorisio et al., 2019; Boehmer et al., 2020), though no direct observation of vagus nerve activities due to upper body vibration exist. Hence, further experimental evidence is required to confirm the intervention of vagus nerves on emotional effects of vibration.

We hypothesized that vibratory stimuli to the thoracoabdominal region affect the emotional experience through the vagus nerves distributed in that region. To investigate this hypothesis, we compared the impacts of vibratory stimulation on fear while watching tragedy movies between two body parts: the fingers and the thoracoabdominal region. We selected the fingers for comparison because they are distant from the thoracoabdominal region and exhibit the highest tactile sensitivity in the body. If our hypothesis holds, that is, the vagus nerves in the thoracoabdominal region are mechanically activated and evoke emotional changes, subsequently, thoracoabdominal stimulation would lead to more intense emotions than finger stimulation. Nonetheless, this study does not exclude other hypothetical mechanisms in part, because it does not pursue vagal activities in an electrophysiological manner.

Previously, Fukushima et al. (2014) compared the effects of vibratory stimuli between four sites: the forearm, fingers, back, and auricle, and found no differences in physiological responses by site. They used a small vibrator to stimulate the skin on the back and did not aim to stimulate the vagus nerves in the body. To the best of our knowledge, this study is the first attempt to compare the subjective and physiological responses of the thoracoabdominal and other body parts to investigate the potential mediation of mechanically activated vagus nerves on human emotions.

2. Method

2.1 Apparatus

A voice coil motor (Vp604, Acouve Lab, Japan) was used to generate the vibrations. As shown in Figure 1, the voice-coil motor was placed in contact with the epigastric fossa using a vest. Additionally, the participants wore a corset over the vest such that the body and voice coil motor were in close contact with each other. To stimulate the fingers, the participants grasped the displacement-generating part of the voice coil motor with the five finger pads of their dominant hand.

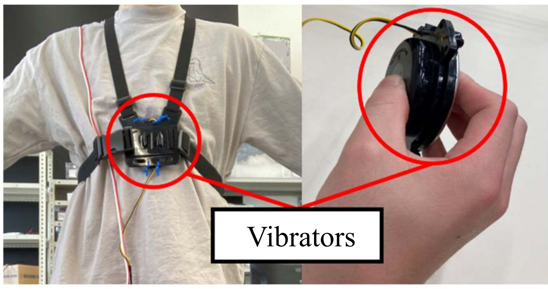

Figure 1: Vibrators on thoracoabdominal part and fingers.

A skin electrical activity measurement unit (AP-U030m II, Nihon Santek, Japan; time constant: 5 s, active range: 0.032–15 Hz) and an amplifier for skin conductance measurements (MaPI720CA, Nihon Santek, Japan) were used to measure the skin conductance response. Electrodes were placed on the palmar surface of the second and third digits opposite to the participant's dominant hand. The sampling frequency was 1000 Hz.

Audiovisual stimuli were played using a signage player (BrightSign/HD220; BrightSign, Inc., United States). The videos were presented on a 21-inch monitor approximately 60 cm from the participants' eyes. Audio stimuli were presented via headphones.

2.2 Stimuli

Horror movies were used as the audiovisual stimuli. Each movie included a jump-scare scene in which monsters suddenly appeared along with sounds to evoke fear. We used six movies of 2–3 min in length that were judged to be sufficiently horrible by the authors and members of the authors' research team.

Vibratory stimuli were presented at the start of the jump-scare scene, and the same vibration stimuli were used in all the movies. The frequency of the vibration was 70 Hz, and the duration was 0.7 s, referring to (Makioka et al., 2022) where subjective fear against horror movies were enhanced by vibratory stimuli to thoracoabdominal part. The amplitude continued to increase for 0.4 s from its onset, and the maximum acceleration of the vibration was 26.2 m/s^2. Regarding amplitude, this corresponded to 135 μm. Thereafter, it decreased linearly.

2.3 Procedures

Before the experiment, the participants watched a horror movie that was not used in the main experiment and experienced vibratory stimuli to the fingers and thoracoabdominal regions to familiarize themselves with these stimuli. In the main experiment, individual participants watched each of the six movies in one of three conditions: no vibratory stimuli, stimulation to the fingers, and stimulation to the thoracoabdominal part. The combination and order of the vibratory conditions and movies were counterbalanced among participants. Hence, each participant watched the six different movies in total with two for each condition. During the experiment, participants wore a vest and grasped the voice coil motor. Hence, they did not know the vibratory conditions that they would receive. After watching each movie, the participants indicated the intensity of fear at the jump-scare scene using a 9-point Likert scale. To ensure that the participants were in a stable physiological condition, they rested for at least 90 s, until the skin conductance response was stable, before viewing another movie.

2.4 Participants

Twelve paid university students in their twenties (nine males and three females), who were unaware of the purpose of the experiment, participated in this study. All the participants provided written informed consent.

2.5 Analysis

The amplitudes of the skin conductance response and the subjective evaluation scores were compared between the stimulus conditions. The amplitude of the skin conductance response is the difference between the value immediately before it started rising, after the jump-scare scene, and the subsequent local maximum, which was typically observed within a few seconds after rising. The subjective evaluation score was the intensity of fear as answered by the participants on a 9-point Likert scale. All values were standardized within participants (*z*-scores), and then averaged within each stimulus condition for individual participants. We applied one-sample *t*-test (*ttest*, Matlab 2023a, Mathworks, USA) to each pair of the three vibratory conditions, that is, without, finger, and thoracoabdominal conditions, with a Bonferroni correction of factor 3 ($_3C_2$). We could not record skin conductance responses from three of the 12 participants, potentially because of their skin conditions. Therefore, we excluded their skin conductance responses from our analysis. Hence, data from nine participants were used to analyze the skin conductance responses.

3. Results

Figure 2 (a) shows the normalized amplitude of the skin conductance response for each stimulus condition. The thoracoabdominal condition significantly increased the amplitudes of the skin conductance response more than the no-stimulus condition ($t(8)=5.02$, $p=3.1\times10^{-3}$), $d=1.67$), whereas, no significant differences were observed between the finger and thoracoabdominal conditions ($t(8)=2.18$, $p=0.18$, $d=0.73$) and the finger and no-stimulus conditions ($t(8)=2.28$, $p=0.15$, $d=0.76$).

Figure 2 (b) shows the subjective scores normalized by the stimulus conditions. The subjective fear scores for the thoracoabdominal condition were greater than those for the no-stimulus conditions ($t(11)=5.23$, $p=8.4\times10^{-4}$, $d=1.51$) and finger conditions ($t(11)=3.27$, $p=0.022$, $d=0.94$), whereas no significant difference was seen between the finger and no-stimulus conditions ($t(11)=1.09$, $p=0.90$, $d=0.31$).

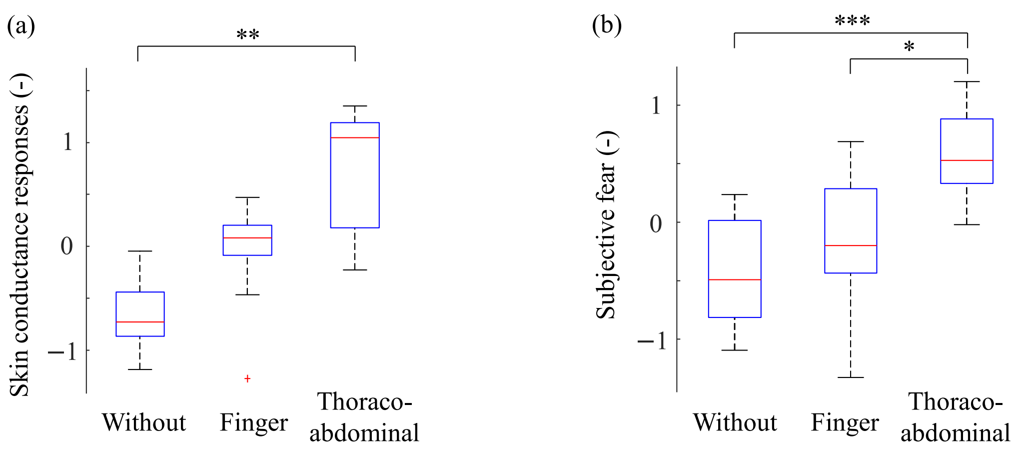

Figure 2: Box plots of (a) the normalized skin conductance amplitudes and (b) subjective ratings. *, **, and *** indicate the significant differences at $p<0.05$, 0.01, and 0.001, respectively, with Bonferroni correction.

4. Discussion

We hypothesized that vibratory stimuli to the thoracoabdominal region would affect emotional experiences via the vagus nerve activation. Based on this hypothesis, a thoracoabdominal part would be a more effective site than the fingers. The significant effects of vibration were observed only for the thoracoabdominal part in comparison with the no-stimulus condition and these results are consistent with the hypothesis, whereas we did not find out significant differences in the skin conductance responses when comparing the two body sites in the statistical tests. Although this study used horror videos, in general, the effects of vibration are expected for other types of emotionally evocative videos. Because we did not observe vagus nerve activity in our study, the experimental results do not exclusively support this hypothesis. Nevertheless, as earlier studies (Addorisio et al., 2019; Boehmer et al., 2020) have suggested, mechanical stimuli may activate the vagus nerves. To endorse our hypothesis further, it would be meaningful to compare a condition in which the external ear is stimulated with the three conditions investigated in this study. The vagus nerves also run through the external ears, and vibratory stimuli to the external ears may cause effects similar to those caused by thoracoabdominal stimulation. Further, the gender balance of participants will be considered for the potential differences in the effects by gender.

Ethics Statement

The study protocol was approved by the Ethics Committee of Hino Campus, Tokyo Metropolitan University (H22-014).

Author Contributions

TM: conceptualization, material preparation, experiment, analysis, and writing manuscript. SO: conceptualization, supervision, and editing manuscript. All authors contributed to manuscript revision and approved the submitted version.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

Addorisio, M. E., Imperato, G. H., de Vos, A. F., Forti, S., Goldstein, R. S., Pavlov, V. A., van der Poll, T., Yang, H., Diamond, B., Tracey, K. J., & Chavan, S. (2019). Investigational treatment of rheumatoid arthritis with a vibrotactile device applied to the external ear. *Bioelectronic Medicine*, *5*(4), 24–25. https://doi.org/10.1186/s42234-019-0020-4

Boehmer, A. A., Georgopoulos, S., Nagel, J., Rostock, T., Bauer, A., & Ehrlich, J. R. (2020). Acupuncture at the auricular branch of the vagus nerve enhances heart rate variability in humans: An exploratory study. *Heart Rhythm O2*, *1*(3), 215–221. https://doi.org/10.1016/j.hroo.2020.06.001

Branje, C., Russo, F., Nespoli, G., & Fels, D. (2014). The effect of vibrotactile stimulation on the emotional response to horror films. *Computers in Entertainment*, *11*(1), 1–13. https://doi.org/10.1145/2543698.2543703

Damasio, A. (2003). Feelings of emotion and the self. *Annals of the New York Academy of Sciences*, *1001*(1), 253–261. https://doi.org/10.1196/annals.1279.014

Fukushima, S., Aou, K., Nakata, A., & Kajimoto, H. (2014). Shindo: Maginification of emotion by auricular tactile stimulation synchronized with sound, *Transactions on Virtual Reality Society of Japan*, *19*(4), 467–476. (in Japanese) https://doi.org/10.18974/tvrsj.19.4_467

Karafotias, G., Teranishi, A., Korres, G., Eyssel, F., Copti, S., & Eid, M. (2017). Intensifying emotional reactions via tactile gestures in immersive films. *ACM Transactions on Multimedia Computing, Communications, and Applications*, *13*(3), 29. https://doi.org/10.1145/3092840

Makioka, T., Okamoto, S., & Tara, I (2022). Fear magnified by vibratory stimuli to the upper-body at predictive horror scenes, *Proceedings of IEEE 11th Global Conference on Consumer Electronics*, 570–572. DOI: 10.1109/GCCE56475.2022.10014187

Sakurai, S., Katsumura, T., Narumi, T., Tanikawa, T., & Hirose, M. (2014). Evoking emotions in a story using tactile sensations as pseudo-body responses with contextual cues. *Proceedings in International Conference on Human Interface and the Management of Information*, 241–250. https://doi.org/10.1007/978-3-319-07731-4_25

Tatsuki MAKIOKA (Non-member)
He received his BS and MS degrees from Tokyo Metropolitan University in 2022 and 2024, respectively. His research interest includes affective engineering.

Shogo OKAMOTO (Member)
He received his Ph.D. in Informatics from Tohoku University. He has been a professor at Department of Computer Science, Tokyo Metropolitan University after serving as an associate professor and assistant professor at Department of Mechanical Systems, Nagoya University. His research interests include haptics, assistive systems, extended reality, and affective computing.