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RESEARCH ARTICLE

Emohance: Enhancing Emotional Arousal in Interactive Content via Real-Time Vibratory Feedback

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ABSTRACT Delivering mechanical vibratory stimuli to the upper body in synchronization with audiovisual content can enhance emotional experiences. Previous studies on emotion amplification have primarily focused on videos with predetermined emotional content and timing. This study extends the application to interactive content, where the emotional narrative dynamically changes based on user interaction. We propose a novel approach that provides real-time vibratory feedback to the thoracoabdominal region in response to increases in a user's skin conductance response (SCR), thereby amplifying emotional arousal. A total of 27 participants were involved in the study, engaging in two distinct types of games: an action game and a suspense-puzzle game. Using a within-participants design, we compared conditions with and without vibratory feedback during gameplay. The results showed a significant increase in self-reported emotional arousal with vibratory feedback. In the action game, subjective frustration and excitement were significantly enhanced, while in the puzzle game, tension was amplified. Additionally, in the action game, the number of peaks and variability of SCR signals increased significantly under the vibratory feedback condition. These findings establish a foundation for technologies aimed at augmenting human emotional experiences during interactive content engagement.

INDEX TERMS Skin conductance response, emotional haptics, biofeedback.

I. INTRODUCTION

Beyond traditional audiovisual enhancements, increasing attention has been given to methods that stimulate sensory modalities other than vision and hearing to enhance immersion and emotional experiences. For instance, Lemmens et al. [1] and Karafotias et al. [2] demonstrated that providing vibratory stimuli through jackets equipped with vibratory actuators, synchronized with emotionally significant scenes, enhanced both immersion and presence in the content. Similarly, Tara et al. [3] and Makioka and Okamoto [4] showed that vibratory feedback applied to the upper body, synchronized with horror and sports scenes, respectively, amplified subjective ratings of fear and excitement. Numerous studies have explored similar approaches, using mechanical stimulation—including vibrations applied to the upper body and hands—to modulate emotional experiences during the viewing of videos and music [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17].

The principle of emotion amplification via vibratory stimuli has been theorized in relation to the mechanisms of emotion arousal [18], [19], [20], [21], [22], [23]. When emotional stimuli, such as audiovisual information, are processed by the brain, they modulate autonomic and endocrine activities, leading to physiological responses. These bodily responses are integrated with audiovisual stimuli via the thalamus, which subsequently mediates their influence on

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neural pathways associated with emotional processing. This framework aligns with the argument that emotions arise from the perception of bodily changes in response to external stimuli, as proposed by James [24]. Based on this model, it is hypothesized that modulating physiological responses in conjunction with audiovisual stimuli can serve as an effective method for emotional regulation.

One proposed mechanism underlying this effect involves the vagus nerve, which transmits information about visceral states to the brain and indirectly modulates endocrine activity through the regulation of neuropeptide and hormone release. The relationship between visceral/interoceptive sensations, interoceptive awareness, and emotional processing has been well-documented [20], [23], [25], [26], [27], [28], [29], [30], [31], [32]. For example, Makioka and Okamoto [4] demonstrated that mechanical stimulation of the thoracoabdominal region—where the vagus nerve runs—is more effective in modulating emotional experiences than tactile stimulation applied to the fingertips, which are typically more sensitive to vibratory stimuli. These findings suggest that the emotion-amplifying effects of vibratory stimulation observed in previous studies are underpinned by these physiological mechanisms.

In addition to visceral and interoceptive pathways such as the vagus nerve, vibrotactile stimulation in the thoraco-abdominal region also engages cutaneous mechanoreceptors. Stimulation of these receptors can itself serve as an affective stimulus, as shown in research on affective touch [33], [34] and in recent work demonstrating the emotional effects of vibrotactile patterns [9], [12].

Previous methods for emotion amplification through mechanical stimulation have primarily been applied to audiovisual content where the type and timing of emotional arousal are predetermined, such as films and music. For instance, in horror films, mechanical stimuli were synchronized in advance with predefined fear-inducing scenes [3], [5]. This study aims to expand the scope of such methods to interactive experiences, including games and interactive media, where the narrative and emotional progression are not predetermined. Specifically, we seek to develop a system that dynamically enhances emotional experiences in real time through vibratory stimulation.

To achieve this, we developed a real-time vibratory feedback system that monitors skin conductance, a physiological marker of emotional arousal, as shown in Fig. 1. Skin conductance reflects changes in electrical resistance due to sweat secretion, which increases with physiological arousal [35], [36], [37], [38]. It has been widely used as a marker of bodily arousal in response to stimuli and is associated with stress, decision-making, pleasure, anger, fear, and excitement [39], [40], [41], [42], [43]. In addition to the tonic component of skin conductance, known as the skin conductance level (SCL), the phasic component, referred to as the skin conductance response (SCR), is also used. SCR shows rapid fluctuations that typically begin 1–3 s after stimulus presentation and reach a peak within another

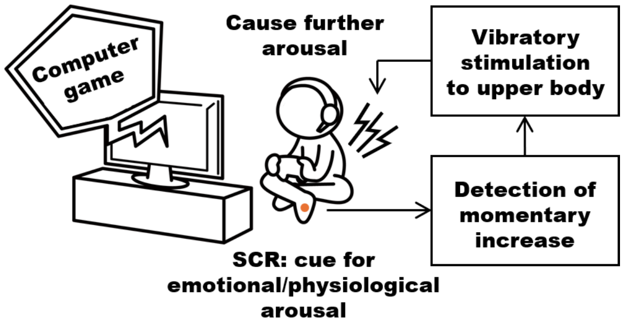

FIGURE 1. Concept of the system tested in this study. On the detection of momentary increase in skin conductance response (SCR), vibratory feedback is applied to the upper body to evoke further arousal.

FIGURE 2. Vest with two voice coil motors. Each contacted the epigastric fossa and its back side, T10 vertebra. Adapted from [35].

1–3 s [44], [45]. This temporal responsiveness makes SCR well-suited for capturing dynamically evolving emotional states within a timescale of a few seconds [38], [46]. Based on this principle, we designed a system that detects increases in SCR and promptly delivers vibratory stimulation to the thoracoabdominal region, reinforcing the associated emotional experience.

This study extends our previous research [35]. In the prior study, we evaluated the effectiveness of the proposed system with 10 participants, focusing on a single action game (Game 1 in this study). In the present study, we analyze data from 15 participants, including those from the previous experiment. Additionally, we report findings from an additional game (Game 2, suspense-puzzle game) to further validate the system. Since these two games differ in nature, comparing their results allows for a comprehensive assessment of the system's effectiveness. This broader evaluation provides a more generalizable understanding of how real-time vibratory feedback based on momentary increases in SCR influences emotional experiences.

II. METHOD

A. APPARATUS

SCR was measured using a skin electroactivity measurement unit (AP-U030mII, Nihon Santeku Co., Ltd., Osaka, Japan; time constant: 5 s) and an amplifier (MaP1720CA, Nihon Santeku Co., Ltd., Osaka, Japan) with Ag/AgCl electrodes (SMP-300m, Mets Inc., Tokyo, Japan).

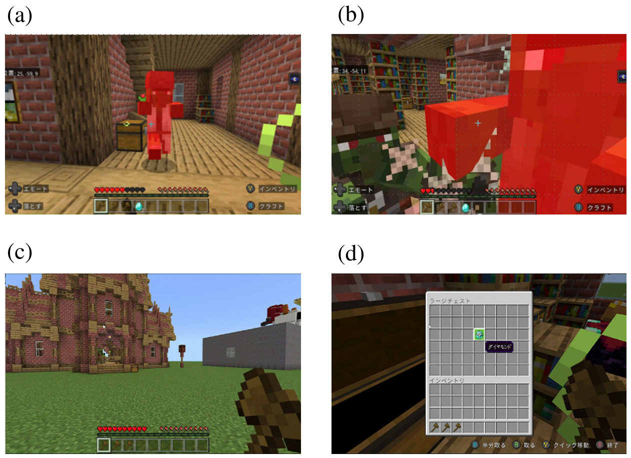

FIGURE 3. **Game 1–Treasure hunting and combat game developed in Minecraft. (a, b) Combat scenes with enemy characters. (c) View from the starting point. (d) Treasure chests placed inside the house. Adapted from [35].**

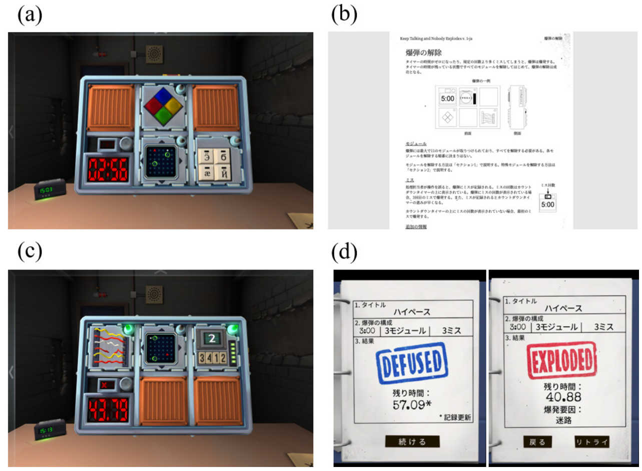

FIGURE 4. **Game 2–Bomb disarming game. The participant and experimenter collaboratively disarm the bomb through verbal communication within a 180-s time limit. (a) The game interface operated by the participant. (b) The disarmament manual, accessible only to the experimenter. (c) The bomb with two out of three tasks completed. (d) The result screen.**

Vibratory stimuli were delivered via two voice-coil motors (p604, Acouve Laboratory, Inc., Tokyo, Japan) driven by an audio amplifier (FX202A/FX-36A Pro, North Flat Japan Co., Ltd., Izumiohtsu, Japan). As shown in Fig. 2, the voice-coil motors were secured to an adjustable vest to ensure firm contact with the epigastric fossa and the T10 vertebra region. We targeted the thoraco-abdominal region because it contains major visceral organs. Compared with distal body sites such as the hands, this region allows for stable, unobtrusive vibrotactile stimulation without distracting the participant from the task. Within this area, we selected the epigastric fossa and T10 because they provide a broad, stable contact surface, are less affected by breathing motion, and have been shown to be effective in enhancing arousal-related responses in prior studies using similar vibrotactile stimulation [3], [4].

Both the skin conductance measurement unit and the voice-coil motors were connected to a signal acquisition device (NI USB-6211, National Instruments Corp., TX, USA) and controlled via MATLAB (R2023a, MathWorks, Inc., MA, USA) using the Data Acquisition Toolbox. The sampling and control frequency was set at 2 kHz.

The game visuals were presented on a 21-inch display positioned 60 cm in front of the participant's head, while audio was delivered through headphones. Participants held and operated the game using a controller (Xbox Wireless Controller, Microsoft Corporation, WA, USA) with both hands.

B. GAMIFICATION: INTERACTIVE CONTENTS FOR AUDIOVISUAL STIMULI

To introduce audiovisual stimuli with unpredictable scenarios, this study employed gamification. Games inherently evoke a range of emotions, including frustration, excitement, tension, and enjoyment. Additionally, since emotionally charged events are triggered interactively based on user actions, the stimuli presented in each trial varied. Two different games were used in the experiment to evaluate the effects of real-time vibratory feedback. Game 1 is an action game involving combat with computer-controlled enemies, while Game 2 is a suspense puzzle game incorporating time pressure and human-to-human communication.

1) GAME 1: TREASURE HUNTING AND COMBAT GAME

The first game was a first-person-perspective treasure-hunting and combat game created in Minecraft (Microsoft Corporation, WA, USA). The objective was for players to collect as many hidden gems as possible within the game stage. The game scenes are shown in Fig. 3. The game environment consisted of a three-story dungeon, where computer-controlled enemy characters appeared randomly to attack and obstruct the player's avatar (Fig. 3(a, b)). When attacked, the avatar's life points decreased, and if all life points were lost, the avatar was respawned at the starting point outside the house (Fig. 3(c)).

Players could use weapons equipped by their avatars to attack enemies, and each enemy required five to six attacks to be defeated. The combat interactions were designed to evoke various emotions, such as excitement, frustration, enjoyment, and a sense of superiority (dominance). Inside the house, four to six treasure chests were randomly placed on each floor, containing collectible gems and other items. Opening a treasure chest had the potential to evoke relief, enjoyment, excitement, or disappointment in participants.

2) GAME 2: BOMB DISARMING GAME

Game 2 was a bomb disarming game, Keep Talking and Nobody Explodes (Steel Crate Games, Inc., Ottawa, Canada). This game required collaborative interaction between two players: the participant, who attempted to disarm the bomb, and the experimenter, who provided instructions. Fig. 4 shows the game interface.

At the start of the game, a timer (located in the bottom left corner of Fig. 4(a)) was activated, counting down from three minutes. To prevent the bomb from exploding, the participant had to successfully deactivate all assigned tasks (modules) attached to the bomb. The specific disarming procedures for each module were documented in a disarmament manual (Fig. 4(b)), which was available only to the experimenter. During the experiment, the participant and the experimenter were prohibited from viewing each other's screen. Instead, they communicated verbally, with the participant describing the modules and components of the bomb, while the experimenter used the manual to determine the correct disarming procedure. The experimenter then provided verbal instructions, which the participant followed to execute the necessary operations. The experimenter was experienced with the game and maintained consistent communication methods across participants. The assigned modules were randomly determined for each trial. To successfully complete the game, the participant had to disarm all three modules within 180 s. If the timer reached zero or the participant made three incorrect attempts, the bomb exploded, resulting in a failed attempt.

Throughout the bomb disarming task, participants experienced heightened emotional arousal, including excitement, anxiety, and tension. Additionally, the success or failure of each task evoked emotional responses such as frustration, relief, or joy.

C. VIBRATORY STIMULI

As stated in Section I, delivering vibratory stimuli at moments when emotional arousal is expected can enhance the intensity of those emotions. In previous studies, these timing points were predefined. However, in this study, where multiple types of emotions are elicited at random moments, we monitored SCR to dynamically determine the timing of vibratory stimulus delivery.

SCR is a physiological signal that reflects bodily arousal [39], [40]. It is associated with arousing emotions such as excitement and fear. SCR exhibits a rapid response, typically beginning 1–3 s after stimulus presentation, peaking within another 1–3 s, and then gradually decaying [44], [45]. In this study, vibratory stimuli were triggered immediately upon detecting a sharp increase in SCR, indicating the onset of emotional arousal.

As shown in Fig. 5(a), the vibratory stimulus was initiated when SCR exceeded a threshold compared to the average SCR value over the past three seconds. The threshold was determined based on the peak value of spontaneous SCR activity [45] measured during a 60-s resting period before the experiment, and it was adjusted within the range of 0.005–0.03 μS. The triggering process was performed at 100 Hz. Once activated, the vibratory stimulus lasted for 2 s, followed by a 2-second refractory period before another stimulus could be delivered. This interval was introduced

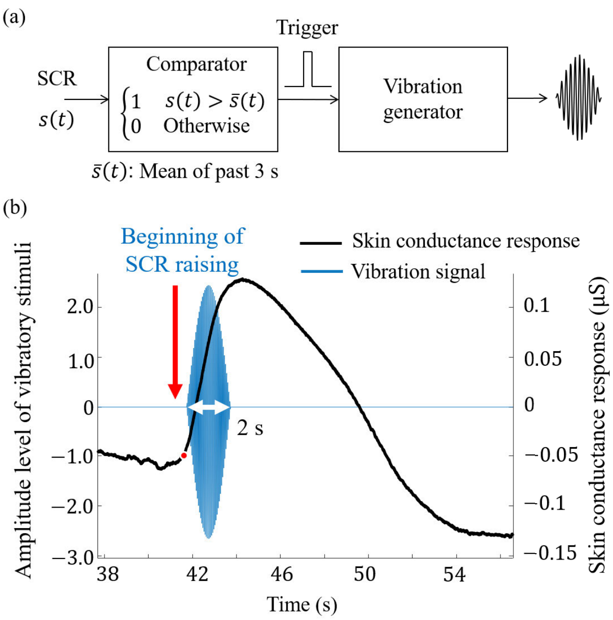

FIGURE 5. Vibratory feedback. (a) Schematic of vibration triggering. (b) Example of vibratory feedback initiated by an increase in SCR. The black line represents the SCR signal, and the blue line represents the vibration output. Adapted from [35].

to prevent excessively frequent stimulation, which could be perceived as disruptive. The vibratory stimuli were repeatedly delivered under these conditions until the game ended. On average, vibrations occurred 16.2 and 16.8 times per session (S.D. = 6.9 and 8.4 times) for Games 1 and 2, respectively.

Fig. 5(b) illustrates the waveform of the vibratory stimuli applied to the upper body. The vibration consisted of an 80-Hz sinusoidal wave lasting 2 s, a frequency shown to be effective in previous studies [3], [4]. The amplitude of the vibration followed a sinusoidal function over time, reaching its maximum intensity after 1 s and then gradually decaying over the following second.

D. PARTICIPANTS

Twenty-seven students from Tokyo Metropolitan University participated in the experiment without prior knowledge of its purpose. All participants provided informed consent before the experiment. Of these, 15 participants (5 females and 10 males, aged 22–25 years) took part in Game 1 (power = 0.82 at effect size $d_z = 0.8$ for a paired two-tailed t-test), and 12 participants (5 females and 7 males, aged 22–25 years) took part in Game 2 (power = 0.71 at effect size $d_z = 0.8$ for a paired two-tailed t-test). Power analyses were conducted using G*Power 3.1 [47].

E. PROCEDURES

Ten minutes before the experiment, participants were fitted with electrodes for SCR measurement on the inner side of the left foot, as shown in Fig. 5. Since participants operated the

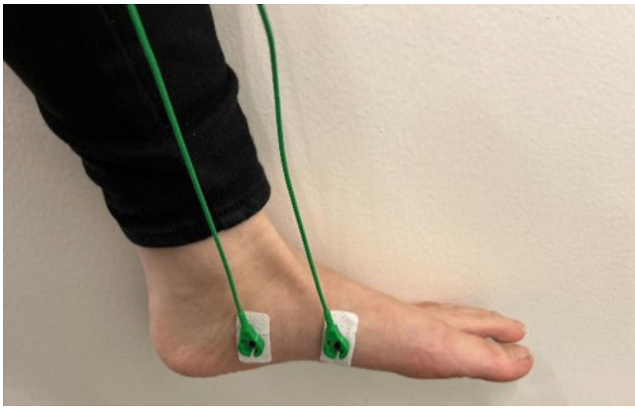

FIGURE 6. Electrodes position to measure SCR instead of fingers.

controller with both hands, measuring SCR from the fingers was impractical. The inner foot region serves as a viable alternative for SCR measurement [48], [49]. Participants were instructed to keep their foot still during the experiment to prevent SCR fluctuations caused by changes in electrode contact. Simultaneously, participants wore the vest equipped with vibratory actuators, as described in Section II-A.

Before the main experiment, participants completed a 180-s practice session to familiarize themselves with the game controls. This was also intended to prevent the large initial adaptation effect when playing the game for the first time. After the practice, they remained at rest for 60–120 s to allow their SCR to stabilize before starting the experiment.

During Game 1, participants played for 150 s. In Game 2, they attempted to disarm the bomb, with a maximum gameplay duration of 180 s. These relatively short sessions were intended to minimize within-session adaptation, as longer durations could increase the likelihood that participants habituate to emotional events and experience reduced emotional responses over time. After completing the game, participants evaluated the emotions they experienced during gameplay. Each participant underwent two experimental conditions: one in which vibratory stimuli were applied to the thoracoabdominal region when SCR increased and another in which no vibratory stimuli were delivered. The order of these conditions was counter-balanced, following a within-participants design.

F. SUBJECTIVE EVALUATION ITEMS

After completing the game, participants evaluated the emotions elicited during their gameplay experience.

For Game 1, the following 10 attributes were assessed: dominant, excited, confused, tense, relieved, angry, disappointed, joyful, frustrated, and relaxed. For Game 2, six attributes were evaluated: excited, joyful, confused, tense, relieved, and frustrated. These descriptors were selected based on the circumplex model of affect [50], [51]. To determine the evaluation terms, a group of six individuals, including the authors and their colleagues, selected applicable adjectives from a list of 26 adjectives using a choose-all-that-apply method. Terms that received at least five votes were included in the experiment. Dominance was defined as the feeling of command or superiority, such as when a participant successfully defeated an enemy. Frustration was defined as the feeling of resentment when things did not go as planned. Tension was defined as a state of feeling tense and upset. No specific definitions were given to the other adjective items. Four attributes used exclusively in Game 1 (dominant, relaxed, disappointed, and angry) were deemed not applicable to Game 2. Even if these attributes had been rated in Game 2, their scores would likely have been close to zero.

Before the experiment, participants were provided with definitions for each evaluation term. After the game, they rated the intensity of each emotion experienced during gameplay on a 9-point scale from 0 to 8. A rating of 0 indicated that the emotion was never felt at any moment during the game, while ratings from 1 to 8 represented the maximum intensity of the emotion if it was experienced at least once.

G. DATA ANALYSIS

To compare subjective evaluations between conditions with and without vibratory stimuli, paired two-tailed t-tests were applied to the scores of each attribute. The p-values for Game 1 and Game 2 were adjusted using the Bonferroni correction with correction factors of 10 and 6, respectively.

For SCR analysis, four types of feature values were calculated for each sample. For this purpose, SCR peaks were defined based on the following criteria:

- A peak had to be at least 0.01 μS higher than the local minimum between the nearest preceding and following peaks.
- The duration for which the SCR value exceeded half of the peak amplitude had to be between 2 and 20 s.

To identify peaks, we used the findpeaks function in MATLAB (2024a, MathWorks, Inc., MA, USA).

Following peak detection, four features were calculated: number of peaks, mean peak value, mean peak amplitude, and standard deviation of SCR, following a guideline [45], [52]. Peak amplitude was defined as the difference between the peak value and a baseline value. The baseline was determined as the higher of the two local minima before and after the peak. These feature values were also compared between conditions with and without vibratory stimuli using paired two-tailed t-tests with Bonferroni-adjustment of factor four.

III. RESULTS

Fig. 7 shows the box plots of the intensity scores of emotions reported in Games 1 and 2. Tables 1 and 2 present the corresponding means and standard errors, along with the results of statistical comparisons between conditions with and without vibratory feedback. For Game 1, vibratory feedback significantly increased the scores for excited ($t(14) = 6.58$,

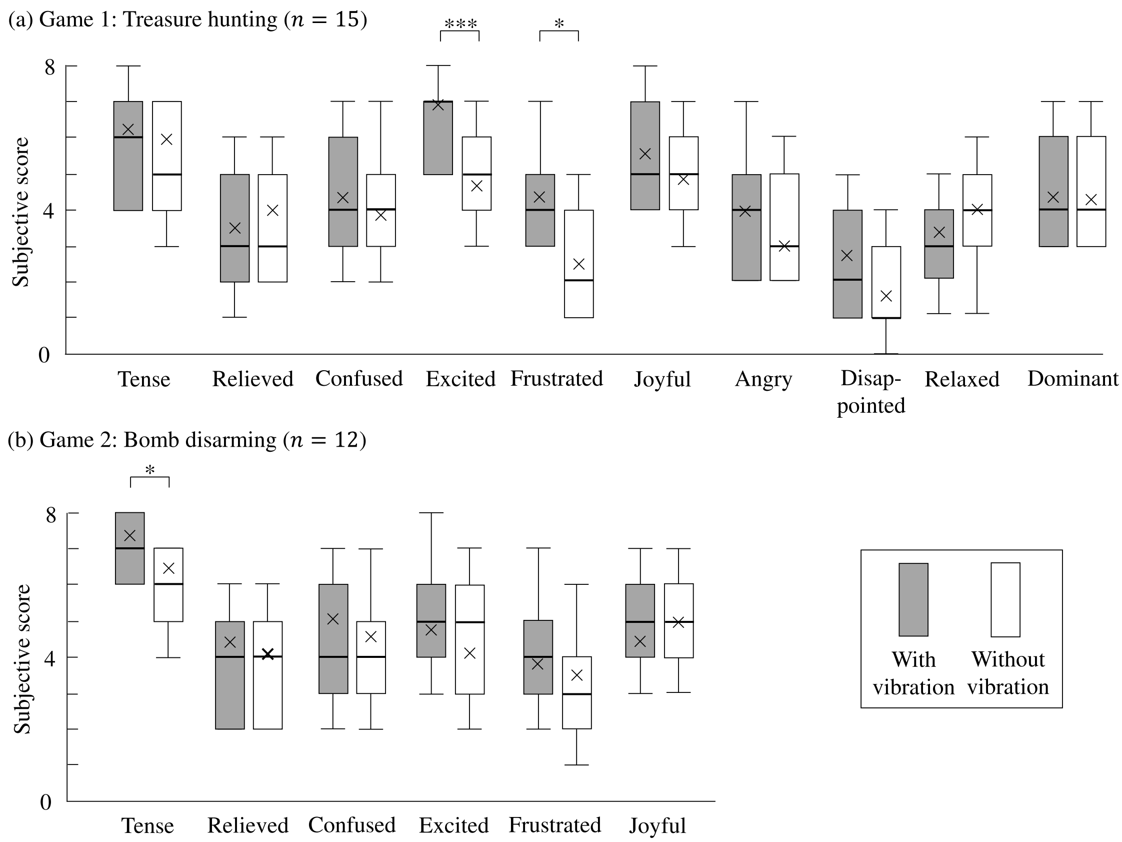

FIGURE 7. Box plots of subjective emotional scores: (a) Game 1 and (b) Game 2. Asterisks denote statistical significance (*: $p < 0.05$; ***: $p < 0.001$). Bold horizontal lines indicate medians, and crosses indicate means. Whiskers represent the minimum and maximum values.

$p < 0.001$) and frustrated ($t(14) = 3.83$, $p = 0.018$). For Game 2, the score for tense was significantly higher with vibratory feedback ($t(11) = 3.52$, $p = 0.028$).

Tables 3 and 4 summarize the mean SCR feature values and their statistical comparisons for Game 1 and Game 2, respectively. In Game 1, the vibratory feedback led to a significant increase in the number of SCR peaks ($t(14) = 4.45$, $p = 0.0022$) and standard deviation of SCR ($t(14) = 3.06$, $p = 0.034$). In Game 2, none of the SCR features showed a significant change due to vibratory feedback.

IV. DISCUSSION

Here, we discuss the effects of vibratory stimulation applied to the thoracoabdominal region, synchronized with SCR increases, on subjective emotional intensity and physiological responses.

According to Fig. 7(a) and Table 1, in Game 1, participants reported that excitement and frustration were enhanced by vibratory stimulation. Similarly, Fig. 7(b) and Table 2 show that in Game 2, the level of tense was significantly increased. Notably, all emotions significantly affected by vibration belong to the category of arousing emotions [50], [51]. In the method of this study, vibratory stimulation was triggered by SCR increases, which are known to be associated with emotional arousal. Furthermore, as discussed in Section I, previous studies have reported that vibratory stimuli can enhance both subjective and physiological arousal when delivered during emotionally salient scenes in movies [1], [4], [5], [6]. Hence, it is reasonable to conclude that vibratory stimulation designed to follow SCR increases amplified arousing emotions. Additionally, in Game 1, vibratory stimulation significantly altered SCR features, providing physiological evidence of its effect. However, no significant effects on SCR were observed in Game 2.

It is important to note that not all arousing emotions were affected by vibratory stimulation. Although joyful and angry are generally classified as arousing emotions, no significant effects of vibration were observed on their scores in Game 1. Nonetheless, there was a trend toward increased scores for anger (unadjusted $p = 0.048$) and joy (unadjusted $p = 0.060$) with vibratory stimulation. One possible explanation is that the game was not designed to elicit strong anger, as it was intended for entertainment. Therefore, it may not be a suitable test environment for assessing the impact of vibration on anger. Regarding joy or happiness, these emotions are positioned between arousal and positive valence, or even further toward the positive valence axis [50], [51]. It is

TABLE 1. Game 1. Emotional attribute scores (means and standard errors) and statistical comparisons. *p*-values were adjusted using the Bonferroni correction with a factor of 10. * and *** indicate statistical significance at $p < 0.05$ and 0.001, respectively.

Attribute	Mean score with vibration (s.e.)	Mean score without vibration (s.e.)	$t(14)$	Adjusted p-value
Dominant	4.33 (0.55)	4.27 (0.44)	0.10	1.00
Confused	4.33 (0.68)	3.83 (0.62)	0.49	1.00
Relieved	3.47 (0.53)	3.93 (0.47)	−0.91	1.00
Angry	3.93 (0.61)	3.00 (0.63)	2.17	0.48
Frustrated	4.27 (0.57)	2.53 (0.54)	3.83	0.018 *
Disappointed	2.67 (0.50)	1.53 (0.42)	3.12	0.075
Joyful	5.47 (0.40)	4.73 (0.37)	2.05	0.60
Tense	6.13 (0.62)	5.87 (0.46)	0.39	1.00
Excited	6.80 (0.28)	4.53 (0.52)	6.58	< 0.001 ***
Relaxed	3.25 (0.35)	4.00 (0.62)	−1.00	1.00

TABLE 2. Game 2. Emotional attribute scores (means and standard errors) and statistical comparisons. *p*-values were adjusted using the Bonferroni correction with a factor of six. * indicates statistical significance at $p < 0.05$ and 0.001, respectively.

Attribute	Mean score with vibration (s.e.)	Mean score without vibration (s.e.)	$t(11)$	Adjusted p-value
Tense	7.33 (0.19)	6.42 (0.34)	3.52	0.028 *
Relieved	4.42 (0.42)	4.08 (0.48)	0.67	1.00
Confused	5.08 (0.61)	4.58 (0.65)	1.73	0.67
Excited	4.75 (0.62)	4.08 (0.71)	1.30	1.00
Frustrated	3.83 (0.84)	3.50 (0.90)	0.57	1.00
Joyful	4.42 (0.69)	5.00 (0.52)	−0.94	1.00

TABLE 3. Game 1's SCR features. *p*-values were adjusted by the Bonferroni correction with a factor of four. * and ** indicate statistical significance at $p < 0.05$ and 0.01, respectively.

SCR features	Mean with vibration (s.e.)	Mean without vibration (s.e.)	$t(14)$	Adjusted p-value
Number of peaks	15.4 (1.98)	10.9 (1.52)	4.45	0.0022 **
Mean value of peaks	0.103 (0.017)	0.0887 (0.021)	1.03	1.00
Peak amplitude	0.137 (0.021)	0.122 (0.025)	1.23	1.00
Standard deviation	0.107 (0.017)	0.0703 (0.012)	3.06	0.034 *

TABLE 4. Game 2's SCR features. *p*-values were adjusted by the Bonferroni correction with a factor of four.

SCR features	Mean with vibration (s.e.)	Mean without vibration (s.e.)	$t(11)$	Adjusted p-value
Number of peaks	13.8 (2.66)	10.9 (2.15)	1.28	0.90
Mean value of peaks	0.087 (9.83×10^{-3})	0.065 (0.013)	2.16	0.22
Peak amplitude	0.11 (9.69×10^{-3})	0.083 (0.14)	2.14	0.22
Standard deviation	0.078 (0.011)	0.058 (0.012)	1.33	0.84

possible that vibratory stimulation, which primarily enhances arousal, may have a weaker effect on emotions strongly associated with positive valence.

Many previous studies have reported that vibratory stimulation to the upper torso can influence the evaluation of video content. Among those that explicitly address the relationship with emotion, fear [3], [4], [5] and excitement [3] were clearly affected by vibration. Both are categorized as high-arousal emotions. Karafotias et al. [2] conducted experiments using a vibrotactile jacket and found that vibration selectively amplified emotions with high arousal on the valence–arousal plane. They suggested that the arousing nature of the vibrotactile stimulation itself accounted for this effect. Similarly, Tajadura-Jiménez et al. [17] used heartbeat-like vibrations and showed that the stimulation affected arousal, but not valence, while participants viewed affective pictures. Sakurai et al. [15] applied pressure rather than vibration to the torso and reported that it increased feelings of tension while participants viewed comics.

In contexts without audiovisual content, vibrotactile stimulation to the hands and arms alone may evoke pleasant emotions [9], [12], [53]. Moreover, vibration can enhance the overall perceived value of audiovisual content, thereby amplifying the sense of fun [1], [10]. These effects may have contributed to individual differences in the interpretation of joy or fun in the present study.

Nevertheless, the majority of previous studies converge on the finding that vibration to the upper torso tends to amplify arousal-related emotions. The absence of a pronounced effect on valence-related emotions in the present study is therefore consistent with earlier findings.

A previous study by the authors using the same Game 1 structure [35] reported a significant increase in both excited and angry, with frustrated and disappointed reaching significance before correction. In contrast, the present study found excited and frustrated to be significant after correction, while angry and disappointed showed only uncorrected significance ($p = 0.048$ and 0.0075, respectively). These differences in emotional attributes may be due to factors such as differences in participant samples, small variations in the random events encountered during gameplay, or sample size effects. Overall, while the effect of vibration on excitement appears robust, the findings for anger and frustration should be interpreted with greater caution. For SCR features, however, the two studies were more consistent, with both reporting significant increases in the number of peaks and the standard deviation in the vibration condition.

There were notable differences in subjective evaluations between Game 1 and Game 2. In Game 1, excitement and frustration were significantly increased by vibratory stimulation, whereas in Game 2, these emotions were not strongly influenced by vibration. Conversely, the tense emotion, which was significantly increased in Game 2, did not show a significant change in Game 1. These differences are likely due to the nature of each game. In Game 2, participants remained in a state of tension for almost the entire 180-s period, as they were constantly engaged in high-stakes decision-making under time pressure. This prolonged state of tension may have diminished the participants' awareness of other emotional variations. These findings highlight the importance of considering content-dependent variations in the effects of vibratory stimulation on emotions. The influence of vibration on emotional experiences may vary, depending on the nature of the interactive content, and this factor should be carefully accounted for in future studies.

The effect of vibratory stimulation on physiological responses varied between the two gamified content types. Similar to the results observed in Game 1, previous studies have reported that vibratory stimulation enhances SCR activity [3], [4], [5], [6]. In Game 2, although there was a slight trend toward increased SCR activation with vibration, the effect was not statistically significant. One possible explanation is that, in Game 2, participants were required to verbally communicate with the experimenter to report the status of the bomb. This listening and speaking activity may have induced a heightened state of arousal, which could have masked the effects of vibratory stimulation on physiological responses [54]. It should be noted, however, that vibratory stimulation significantly increased the tension score in subjective ratings. Such divergence between subjective and physiological measures is not uncommon in affective and psychophysiological research (e.g. [12], [55]), as the two capture partly distinct aspects of emotional processing.

The proposed method has several points for improvement, one of which is the delay in vibratory stimulus presentation. In this approach, SCR responses exhibit a latency of 1–3 s, which can result in feedback occurring after the emotional game scene that triggered the response. Such a delay may hinder the intended emotional amplification effect [3].

In the present study, participants were not informed of the triggering mechanism in advance. Nonetheless, 16 out of 27 participants noticed that vibrations tended to occur during moments of excitement or arousal. Half of these inferred that the timing was related to a physiological signal measured at the foot, while the others assumed that the vibration was either pre-programmed to coincide with specific events (e.g., combat scenes) or manually controlled by the experimenter. Such awareness of the mechanism underlying arousal-inducing stimulation could contribute to individual differences in its emotional effects. Participants who are aware of the principle would be less likely to misattribute arousal induced by the stimulation [23], [56]. It should be noted, however, that such individual effects were not observed in some studies [57] or were observed in different forms in others [58]. All 16 also reported that vibrations sometimes occurred in situations they did not perceive as particularly arousing, such as when their game character was standing still, which may have been due to involuntary foot movements or spontaneous SCR responses.

Despite these observations, none of the participants spontaneously reported perceiving a distinct delay after being informed of the vibration mechanism. This may be because the onset of arousing events in the games was often gradual rather than instantaneous—for example, an enemy appearing and approaching before an exchange of attacks—making it more difficult to notice precise timing differences. Nevertheless, the potential impact of latency on effectiveness cannot be dismissed. While reducing this delay is challenging with SCR-based triggering alone, integrating other real-time indicators of arousal, such as facial expressions or motion cues, may provide a more responsive solution.

Another challenge is the complexity of the stimulation apparatus. Participants wore a vest equipped with vibratory actuators, designed to effectively stimulate interoceptive sensations. However, the voice-coil motors weighed 310 g each, making the vest somewhat burdensome to wear. Additionally, SCR measurement poses practical limitations. The available measurement sites on the body are restricted [48], [49], and electrode-skin contact must remain stable throughout the experiment. Unless these limitations are addressed, applying this method to physically active content, such as sports-related applications, will be challenging. Further, the SCR threshold used in this study was not formally validated. Future work should explore effective methods for determining and optimizing the vibration trigger threshold.

Potential applications of the method proposed in this study extend largely to entertainment, such as theme park attractions. Given its demonstrated ability to amplify high-arousal emotional states, the method may be particularly well suited for applications aiming to intensify excitement and suspense, as well as to enhance patient motivation in healthcare and trainee motivation in physical training programs. Beyond entertainment, the approach could also be applied to enhance emotional engagement in video-based telecommunication and immersive virtual reality experiences, making them more emotionally evocative. Furthermore, it could be utilized in contexts such as empathy training and educational simulations.

V. CONCLUSION

This study examined the effectiveness of a method for enhancing emotional experiences in interactive content through vibratory stimulation applied to the upper body. In this approach, vibration was delivered in real time by detecting momentary increases in SCR during gameplay. Using two types of interactive games with unpredictable scenarios, we compared subjective emotional ratings and SCR activity changes with and without vibratory stimulation. The results suggest that the effects of vibration vary depending on the nature of the game, influencing different types of emotions and physiological responses. However, in certain cases, vibratory stimulation enhanced the subjective intensity of arousing emotions, such as excitement, tension, and frustration, while also tending to increase SCR activity. These findings contribute to the development of video games and virtual reality experiences by offering new insights into the potential of real-time physiological feedback for emotional enhancement.

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