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ORIGINAL ARTICLE

Timing of Vibratory Stimuli to the Upper Body for Enhancing Fear and Excitement of Audio-visual Content

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Abstract: Vibratory stimuli to viewers' upper bodies enhance emotional experiences during audio-visual content. Studies have investigated the effects of stimulation conditions, such as vibration waveform and spatiotemporal patterns. We investigated how the timing of vibratory stimuli affect viewers' skin conductance responses and subjective reports of audio-visual experiences. Vibratory stimuli were administered to the viewers' torso at various timings around a monster's sudden appearance in horror videos, and jump performances in figure skating videos. For horror videos, vibratory stimuli elicited fear. The fear of horror videos was maximized when the vibratory stimuli started simultaneously with the monster's first appearance. For the jump performance scenes in figure skating videos, although the most exciting timing varied by participant, the vibration should be intensified as performers launch off the ice. These findings will help develop entertaining audio-visual content.

Keywords: *Vibratory stimuli, Emotion, Audio-visual contents*

1. INTRODUCTION

Vibratory stimuli are used to enhance the experiences of audio-visual content [1-12]. For example, Lemmens et al. [1] and Karafotias et al. [2] presented vibratory stimuli to viewers' upper bodies during several videos using jackets with vibrators installed and enhanced viewers' subjective ratings for the quality of experiences such as immersion and realism. In addition, Branje et al. [8] reported an increase in average skin conductance levels whilst watching horror videos when converting their soundtracks to vibratory signals and delivering them to viewers' whole bodies.

Most earlier studies reported that the vibratory stimuli increased the subjective rating of audio-visual content. In contrast, the physiological responses did not necessarily increase by vibratory stimuli and depended on content genre [1, 6, 9]. For example, Lemmens et al. investigated how vibratory stimuli changed subjective ratings and physiological responses for various genres of emotionally evocative videos [1]. In their study, irrespective of the emotions evoked by the videos, subjective scores increased due to vibratory stimuli. However, the effects of the vibration on the physiological responses were only apparent in videos that evoked negative emotions such as anger and anxiety.

Vibratory stimuli are composed of various characteristics, such as vibration waveform, body parts to stimulate, and spatiotemporal patterns of vibrators. Earlier studies investigated how these characteristics affect users' emotions or feelings [2, 13-22]. For example, Okamoto et al. [22] reported that a certain vibratory frequency on one's back induced a pleasant feeling. Further, vibration timing can be one of the design parameters because the temporal consistency between multimodal stimuli is a determinant of sensory integration [23, 24]. For example, several tens of millisecond of temporal gap can be recognizable for haptic cues [25]. However, this parameter has not been investigated in earlier studies, in which they matched the commencement of the vibration to emotional scenes partly because most studies utilized the soundtracks or salient visual motions in the videos to determine the timing of the vibratory cues [2-4, 6-8, 10, 12]. Hence, earlier studies do not inform us of the effects of the delay or lead in vibration timing. When the vibration is appropriately timed with the audio-visual content, the vibratory stimuli are associated with events in the videos. However, if the vibration timing dramatically deviates from the audio-visual content, the experience may be tainted because the viewers may not associate the vibratory stimuli with the scene. Therefore, vibration timing is an essential element for enhancing the experiences of the audio-visual content. Thus, to enhance emotional experiences, it will be helpful to understand good timing and an acceptable range of deviations in vibration timing.

This study investigated the effects of the vibration timing on viewers' physiological response and subjective rating of audio-visual content and determined the best

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timing. In the experiment, the vibratory stimuli are administered to viewers' upper bodies in context with emotionally evocative scenes in horror and figure skating videos.

This study extends our previous study [26] that investigated how the vibration timing affected the viewers' excitement to figure skating videos. This study also targets fear in addition to excitement of sports scenes which are both arousing emotions. The former has a negative valence, and the latter has a positive or neutral one. Multiple emotions such as fear and excitement should be investigated to confirm the generality of the study. Furthermore, our previous study [26] failed to discuss individual video differences. The effects of their potential differences should be considered to conclude the effects of vibration on emotional experiences.

This study was approved by the Institutional Review Board, Hino Campus, Tokyo Metropolitan University (#21-46).

2. METHODS

2.1 Apparatus

The audio-visual content was played using a signage player (BS/HD220, BrightSign, Inc., United States) that controls the video in response to external digital signals. The signage player had a 21.5-inch monitor with an aspect ratio of 16:9 and headphones for video and audio output.

The vibratory stimuli were presented by voice coil motors (Vp408, Acouve Laboratory, Inc., Japan). As shown in Figure 1, the vibrators were attached firmly to the left and right sides of the shoulders, chest, abdomen, and waist of participants using a strap vest. All the voice coil motors were actuated synchronously.

Trigger signals to the signage player and voice coil actuators were synchronized using a microcomputer (mbed NXP LPC1768, ARM Ltd., England). The microcomputer output the vibration waveform signals to the vibrators at the predetermined time for each video. The vibratory signals were then amplified by an audio amplifier (FX-2020A+, NFJ North Flat Japan Ltd., Japan) and input to voice coil actuators. The control frequency of the vibration waveform was 1000 Hz.

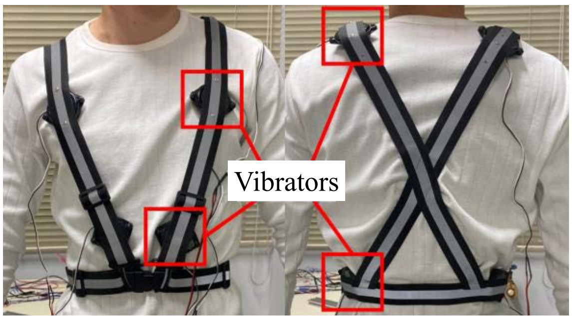


Figure 1: Vibration vest (adapted from [26])
Vibrators were attached firmly to the left and right sides of shoulders, chest, abdomen, and waist of the vest.

We measured the skin conductance responses [27] of viewers' hands when watching horror or figure skating videos. Skin conductance has been used to indicate emotional arousal, including feelings of fear and excitement [27-31]. Furthermore, the skin conductance measurement is suitable for evaluating the viewers' responses to instant stimuli such as monster's appearance scenes and jump performance scenes because it starts rising after the stimulation within 1–2 seconds. We used a measurement unit (AP-U030m II, Nihon Santeku Ltd., Japan) and an amplifier (MaP1720CA, Nihon Santeku Ltd., Japan) to record the skin conductance response. For this measurement, electrodes were attached to the second and third fingers of the viewers' left hand. The signal of skin conductance response was recorded using an oscilloscope (TDS2004C, Tektronics, Inc., United States) at 1000 Hz.

2.2 Audio-visual content

Participants watched five horror videos and six figure skating videos. Each horror video was about two to three minutes long and included a scene where a monster suddenly appeared. The titles of the horror videos were *Blackout, Chain letter, Fear filter, Splat*, and *Cam closer*. Each figure skating video was approximately one minute long and was of different male performers. We selected two performances from the PyeongChang Olympics 2018, three from the Audi Cup of China 2016, and one from the World Figure Skating Championships 2015. Each video started with the beginning of the performance and ended after the first jump performance was completed. The monster's appearance and jump performance scenes, of which moments of beginning could be clearly defined, were used as audio-visual stimuli to evoke viewers' fear and excitement.

2.3 Vibratory stimuli

1) Preliminary experiment to determine the vibratory stimuli

We designed different vibratory stimuli for horror videos and figure skating videos. These patterns were determined by a preliminary experiment with five participants, excluding the authors, where effective vibratory frequency, amplitude profiles, and strength were set through participant agreement. Earlier studies demonstrated that these properties affect feelings [13, 32-34]. The parameters and modulation methods were varied, that is, amplitude or frequency modulation. A set of vibratory stimuli was prepared and based on the results of participant voting for each horror and figure skating video, stimuli for the main experiment were determined.

We modulated the amplitude of the sinusoidal waves at a constant frequency of either 20 Hz, 50 Hz, 70 Hz, and 110 Hz. All the participants agreed that the sounds associated with the vibration at the frequencies greater than 110Hz deteriorated the video contents. Hence, frequencies higher than 110 Hz were not used in the preliminary experiment. The waveforms of the amplitude were either square, triangular, sawtooth, or reverse sawtooth waves. Furthermore, the vibration intensity was controlled at two levels, that is, weak or strong vibration. To reduce the number of stimuli to be tested, we used a cross table with frequency, waveform, and intensity as parameters, and then designed and compared sixteen types of vibratory stimuli. Similarly, we applied frequency-modulated vibration. Frequencies linearly changed from 20 Hz to 110 Hz and from 110 Hz to 20 Hz. Two intensity levels were applied to these frequency-modulated stimuli. In total, suitable stimuli were selected for the main experiment from 20 vibratory stimuli (16 amplitude-modulated + 4 frequency-modulated) through voting by five participants. For each of horror and figure-skating videos, each participant voted for three vibratory stimuli that would enhance the emotional experiences while looking at videos. For each type of videos, one vibratory stimulus gained four votes, of which features are described in Section 2.3 2). Note that through these processes, we did not seek optimal vibrations regarding emotional effects; however, we intended to select reasonably effective vibrations.

2) Vibratory stimuli adopted for the main experiment

For the horror videos, we adopted a frequency-modulated vibration, of which frequency was decreased linearly from 110 Hz to 20 Hz over a second. The voltage amplitude to the voice coils was constant. The maximum acceleration of the vibrators' surface was approximately 150 m/s^2 when the vibration frequency was 110 Hz and 7 m/s^2 for 20 Hz.

We adopted an amplitude-modulated vibration of 70 Hz for the figure skating videos. The amplitude was modulated by a triangular wave, increasing linearly from 0 over 640 ms after onset and decreasing to 0 for another 640 ms. The maximum acceleration of the vibrators' surface was 60 m/s^2 when the vibration amplitude was at its peak.

3) Preliminary experiment to determine presentation timings of vibratory stimuli

The levels of the vibration timing were determined by another preliminary experiment involving the same five participants. At this stage, the vibration was presented in context with several horror or figure skating videos at several timings while shifting forward or backward the onset of the vibration by 100 ms from the reference timing. For the reference timing of the horror videos, the vibration started simultaneously with the monster's appearance. We determined the reference timing of the figure skating videos, where the peak of the vibration coincided with the performer's take-off from the ground. We determined the upper and lower limits, that is, delay and lead, of the vibration timings that the participants could barely associate the vibration with the monster's appearance or jump performance scenes. The intervals between the upper and lower limits were set such that four or all five participants could marginally recognize which of the two neighboring timings was earlier.

4) Presentation timings adopted for the main experiment

For the horror videos, five conditions were adopted. The vibratory stimulus was not administered in one condition. In the other four conditions, the vibrations were differently timed. As shown in Figure 2 (a), for the reference timing, the vibration started simultaneously with the instance of the monster's appearance. In two conditions, vibration onset was shifted to 400 ms earlier or later than the reference. In the last condition, the onset was 700 ms later than the reference.

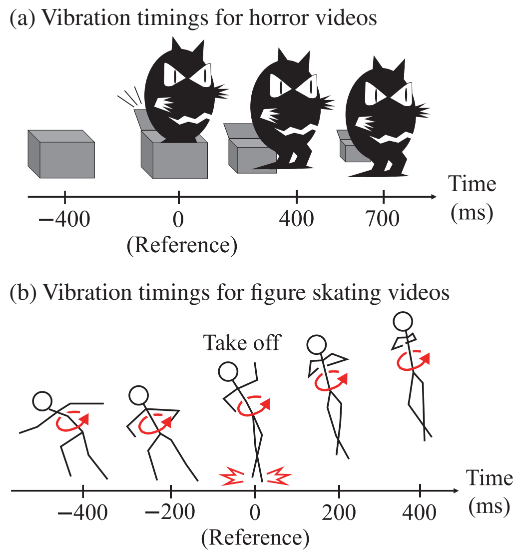


Figure 2: (a) Four vibration timings for horror videos. At the reference time point, a monster suddenly appears. (b) Five vibration timings for figure skating videos (adapted from [26]). At the reference timing, the peak of the vibration amplitude coincides with the performer's take-off from the ground.

For the figure skating videos, six conditions were adopted. In one condition, the vibration was not presented, whereas in another, the vibration was presented so that its peak matched the performer's take-off. As shown in Figure 2 (b), the other four vibration timings included 200 ms or 400 ms earlier and 200 ms or 400 ms later than the reference timing.

2.4 Participants

Eighteen (eight women) and twenty-four (twelve women) university students (mean and standard deviation of ages: 22.0 ± 1.5) participated in the experiment of the horror and figure skating videos, respectively, after providing written informed consent. Nine participants watched both the horror and figure skating videos, and the other participants watched either of them. They had not seen any of the videos used in the experiment and were not aware of the objective.

2.5 Procedures

The horror and figure skating video trials were conducted separately at intervals of at least 30 min. For those who participated in both types of trials, the videos' order, that is, horror or figure skating videos, was randomized.

The participant wore vibration-presenting vests, skin conductance sensors, and headphones, and was seated in a chair during the experiment. The skin conductance electrodes were attached after his/her fingers were wiped with an alcohol sheet and dried. The participant was administered the vibratory stimulus thrice before the experiment began to avoid his/her reactions toward an unfamiliar upper body vibration.

In the experimental trials, the participant watched videos under several conditions of the vibratory stimulus. In the horror video trials, the vibratory stimulus was presented for four of the five videos with different timings. Similarly, in the figure skating video trials, the vibration was presented in five of the six videos. The order and combination of video and vibration conditions were randomized for each participant. Before watching each video, the participant relaxed for at least 3 min. The video was started again only after the skin conductance responses were visually judged as stable.

After watching each video, the participant rated their fear levels in response to the monster's appearance or excitement levels in reaction to the skaters' jump performances. Participants used a 9-point graded scale to rate levels of fear and excitement, respectively, experienced at the monster's appearance during the horror video and the jump performance during the figure skating video. The scale's two extremities were labeled as *only a little excited/scared* to *very excited/scared*. The participants watched either five horror or six figure skating videos in a row. Then, they were encouraged to make the first video of each genre a reference and comparatively rate the succeeding videos.

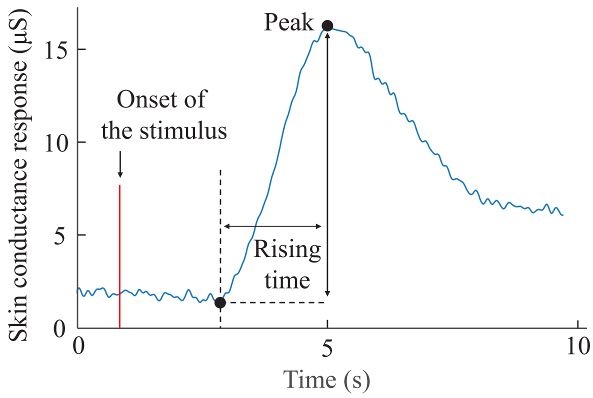


Figure 3: Change in the skin conductance response to a stimulus
The increase in skin conductance response from the commencement of the rising to its peak was used for the analysis.

2.6 Analysis

The skin conductance value starts rising 1–2 seconds after the stimulation and peaks within 1–2 seconds, and tapers after the peak, as shown in Figure 3. We analyzed the increase in the skin conductance response from the commencement of the increase to the peak, which is generally called an amplitude.

We investigated the effects of vibratory stimuli and their timing on skin conductance amplitudes and questionnaire scores. These values were standardized (z-scored) for each participant. Six participants in the horror video trials and five participants in the figure skating trials were excluded from the skin conductance amplitude analysis because they exhibited no response to vibratory and audio-visual stimuli potentially because of their skin and physiological conditions.

The main interest of the present study is the effects of the timing of vibratory stimuli. However, different videos evoked varying levels of fear or excitement. Hence, the videos' effects were explicitly considered. We used two-way ANOVA with the vibration timing and video being two factors to investigate their effects on the skin conductance and questionnaire scores. The statistical analyses were conducted in Matlab (2021b, MathWorks, United States).

3. RESULTS

3.1 Results for horror videos

For the horror videos, Table 1 summarizes the results of two-way ANOVA. As listed in Table 1 (a) and (b), the vibration timing exhibited a significant effect on the skin conductance amplitudes and subjective fear, respectively, whereas the effects of videos and interaction were insignificant. The levels of fear were not very different between the five videos used in the experiment.

Table 1: Summary of two-way ANOVA for horror videos

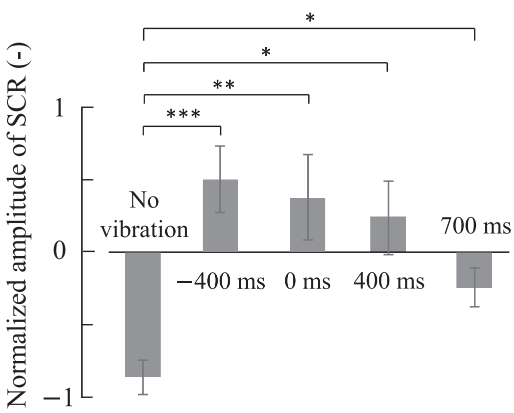
(a) Amplitude of skin conductance response

	d.o.f.	*F*	*p*
Vibration timing	4	5.15	2.3×10^{-3}
Video	4	1.20	0.33
Vibration timing × video	16	0.51	0.93
Error	35		

(b) Subjective feare

	d.o.f.	*F*	*p*
Vibration timing	4	6.90	1.0×10^{-4}
Video	4	2.34	0.065
Vibration timing × video	16	0.61	0.86
Error	65		

(a) Normalized skin conductance amplitudes



(b) Normalized questionnaire scores for fear

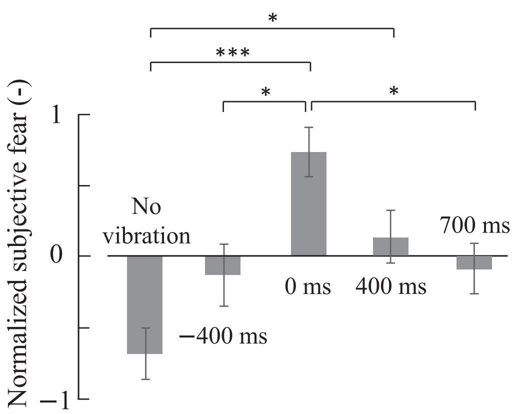


Figure 4: Effects of vibration timings when horror videos were watched

Error bars are standard errors.
*, **, and *** indicate significance levels of $p<0.05$, 0.01, and 0.001, respectively, with Bonferroni correction of factor 10.

Figure 4 shows the means and standard errors of the skin conductance amplitudes and subjective fears by the vibration timing. As post-hoc tests, the amplitudes and subjective fears were compared between all the pairs of timing conditions including no-vibration condition by *t*-tests with Bonferroni correction of factor 10 ($_5C_2$).

As shown in Figure 4 (a), for all the vibratory conditions, the skin conductance amplitudes were greater than that of no-vibration condition indicating that the vibratory stimuli led to the increases of physiological activities irrespective of the temporal gap with the monster-appearance scene.

As shown in Figure 4 (b), the subjective fear was the highest when the vibration ignited with the monster's appearance. The fear levels for no-delay condition (0-ms condition) and 400-ms condition were greater than that for no-vibration condition.

3.2 Results for figure-skating videos

Table 2 shows the results of two-way ANOVA for figure skating videos. For the amplitude of skin conductance response and questionnaire score, the vibration timing was the unique significant factor. The effects of vides were not significant, and the interaction between the vibration timing and video was also insignificant.

Figure 5 (a) and (b) show the means and standard errors of the normalized amplitudes of skin conductance and subjective excitement scores, respectively, by timing conditions. For each pair of the different timing conditions and no-vibration condition, *t*-test was performed with Bonferroni correction of factor 15 ($_6C_2$).

Significant differences in the skin conductance were observed between the no-vibration condition and all conditions with the vibration, which indicates that the vibratory stimuli to the upper body evoked physiological activities. In contrast, no differences were seen between any vibration conditions with different vibration timings.

Regarding the questionnaire scores of excitements, no-vibration condition and −400-ms condition exhibited smaller values than the other conditions with vibratory stimuli. No significant differences were seen between 0-ms, 200-ms, and 400-ms conditions. For these vibratory conditions with zero or greater delays, the questionnaire scores were equally large.

Table 2: Summary of two-way ANOVA for figure-skating videos

(a) Amplitude of skin conductance response

	d.o.f.	F	p
Vibration timing	5	4.82	7.0×10^{-4}
Video	5	2.15	0.068
Vibration timing × video	25	0.97	0.52
Error	78		

(b) Subjective excitement

	d.o.f.	F	p
Vibration timing	5	11.4	7.6×10^{-9}
Video	5	0.28	0.80
Vibration timing × video	25	0.34	0.94
Error	108		

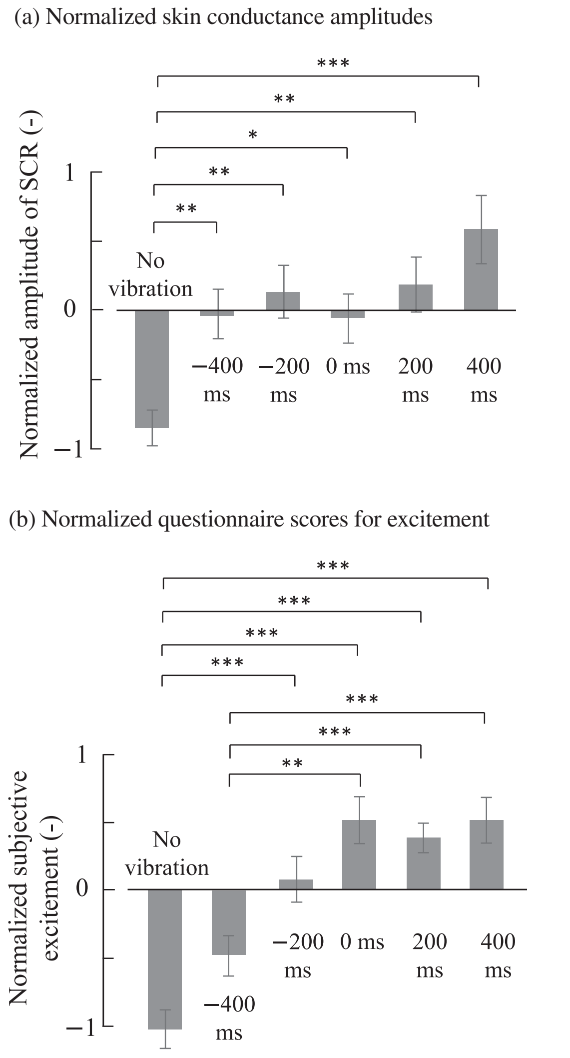


Figure 5: Effects of vibration timings when figure-skating videos were watched

Error bars are standard errors.
*, **, and *** indicate significance levels of p<0.05,0.01, and 0.001, respectively, with Bonferroni correction of factor 15.

4. DISCUSSION

Regarding the questionnaire scores, majority of the vibration conditions led to higher scores than the no-vibration condition for both the horror and figure skating videos. Upper body vibrations increased fear reactions to the monster's appearance and excitement responses when the skaters performed technically difficult jumps. Previous studies have demonstrated that vibratory stimuli enhance emotional experiences and improve the immersive quality of audio-visual content [1-12, 18, 32-34]. However, earlier research has not examined basic emotions such as fear and excitement. These studies primarily investigated arousal and valence and found that vibratory stimuli increase arousal. Fear and excitement are classified as arousing emotions [35], and our results agree with these early studies. Hence, it can be concluded that upper body vibrations impact fear and excitement.

Participants reported the strongest fear reaction for the reference vibration timing, as shown in Figure 4 (b). The fear was the strongest in horror videos when the vibratory stimulus was administered simultaneously with the monster's appearance. The vibration effects became weaker if the timing was shifted by 400 ms. According to introspective reports, when the vibratory stimulus was administered earlier than the reference timing, participants were surprised at the sudden, unexpected stimulus timing; however, the experience of fear was not influenced by the vibration because of their temporal gap. They also reported that the fear was not heightened when the vibration occurred later than the reference timing.

As shown in Figure 5 (b), most participants reported that vibration timing at the reference point or later largely matched the jump performance scenes in figure skating videos. Perhaps the most exciting moment in the figure skating jump performance depended mainly on the viewers' perspectives. Some participants reported that the instance when the performer was in the air was the most exciting. Others stated that the performer's landing, occurring later than all other experimental timing conditions, was most exciting. In contrast, few participants rated timings earlier than the reference point as most exciting. According to participant introspective reports, the vibration started too early for the jump performance scenes when the timing was shifted by 400 ms earlier than the reference point.

One area remaining to be clarified concerns the lack of agreement between various vibration timing effects on skin conductance amplitudes and subjective ratings, especially for the horror videos. For these videos, the correlation coefficient between the standardized skin conductance amplitudes and subjective fear levels was 0.43 ($t = 3.63$, $p = 3.00 \times 10^{-4}$) indicating that the relationships were moderately or weakly consistent. The −400-ms timing was significantly higher than the no-vibration condition for the skin conductance responses. In contrast, as shown in Figure 4 (b), the no-vibration and −400-ms timing conditions were not significantly different for subjective fear. This inconsistency between the skin conductance and subjective fear can be explained by the introspective reports of the participants as aforementioned. They commented that the −400-ms timing startled them because the vibration was unexpectedly earlier than the horrific scene. However, they recognized that such early vibration did not temporarily match the monster's appearance in the video. For the figure skating videos, as shown in Figure 5, all vibration timing effects on skin conductance were significant; however, the −400-ms timing did not significantly differ from the no-vibration condition regarding the subjective excitement. Hence, for the −400-ms timing, the questionnaire and physiological responses mismatched. Nonetheless, in general, the standardized skin conductance amplitudes and subjective excitement levels were moderately consistent with the correlation coefficient of 0.65 ($t = 9.05$, $p < 2.22 \times 10^{-15}$).

We demonstrated the emotional effects of the upper-body vibratory stimulation synchronized with scenes of horror or excitement. However, some limitations remain unaddressed. Regarding the figure skating videos, we found that the moments judged most exciting differed among participants, based on their introspective reports. Figure skaters' jump performance scenes have some unique qualities that may account for this variation. Hence, this study's results related to the figure skating videos may not be directly applicable to other sports videos. We adopted a within-subjects design for the experiment where participants experienced all videos and vibration conditions. Participants could familiarize themselves with the horror and figure skating videos and vibratory stimuli. Between-subjects designs are ideal for avoiding habituation effects. However, it is difficult to compare skin conductance amplitudes among different participants because of substantial individual differences. Furthermore, skin conductance measurement largely depends on electrode contact conditions. Although this study addressed fear and excitement, in general, the types of emotion that can be influenced by upper-body vibration have not been firmly established. In earlier and current studies, some successes have been reported. However, only a few studies producing either negative results or those where emotions could be only minimally altered have been reported. Furthermore, the optimal vibratory stimuli to influence emotions still remain unclear. Nonetheless, we established the effects of the vibration timing, that is, one of the many conditions, as an important condition for successfully influencing emotions.

In earlier studies, the mechanism for the upper body vibration to influence the emotional experiences with audio-visual content has not been thoroughly discussed. We speculate that the vibratory stimulation of the visceral sensation affects the changes in emotional experiences. Visceral or interoceptive stimuli affect emotions [36-39]. Changes in interoceptive sensations caused by mechanical vibration to visceral organs may be attributed to the emotional content of videos. A similar hypothesis was also considered in [39, 40].

5. CONCLUSION

We investigated vibratory stimuli effect when administered to the upper bodies on skin conductance amplitude and subjective emotional experience scores in reaction to horror and figure skating videos. The rated fear and excitement scores in response to the horror and skating videos, and the skin conductance responses became larger when the vibratory stimuli were administered in the expected context at the peak point of fear or excitement. The fear response to horror videos was maximized when the vibration started simultaneously with the beginning of startling scenes. If the vibration timing deviated by 400 ms or more from this timing, the fear experience was not enhanced. Although the most exciting vibration timing for the figure skating jump performance video scenes depended on viewers' perspectives, based on our results, the vibration should be intensified after the skater launches off the ice. This study's findings will be useful for enriching immersive emotional experiences in response to audio-visual content. Once the designers find the best vibration timing, a temporal shift of a few hundred milliseconds must be avoided. Such deviations spoil the viewers' emotional experiences. However, deviations of a few tens of milliseconds might be acceptable. One future research challenge will be to examine the use of videos with prolonged emotional scenes, unlike those used in this study. Long-lasting romantic scenes and rally scenes in tennis games are examples that might be addressed in the future.

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