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Enhancing the experience of film with a wearable tactile/haptic suit

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Abstract
This study investigated whether synchronized, full-body pressure feedback from a wearable suit (the "bubble suit") could enhance audience engagement during film viewing. While vibrotactile haptics have been explored in gaming and Virtual Reality (VR), pressure-based haptics remain unexplored in cinematic contexts. A within-subjects experiment was conducted with 42 participants who viewed two short film clips, one with synchronized pressure feedback delivered via an inflatable wearable suit, and one without. The custom-designed inflatable suit provided pressure across the torso, back, and limbs, controlled by an Arduino system synchronized with on-screen events. After each viewing, participants completed questionnaires measuring immersion, narrative engagement, attention, and realism. Notably, participants' willingness to pay for the experience more than doubled. The haptic feedback also altered character empathy, shifting viewers' emotional focus from the protagonists to side character experiencing the haptic-related event. However, the effects varied between participants, influenced by factors such as the suit's fit and individual sensory interpretation. In conclusion, wearable pressure feedback can significantly enhance the perceived cinematic experience, offering a powerful tool for increasing audience engagement and the perceived value of entertainment. While the findings inform future designs for haptic-enhanced media, key implementation challenges remain, including technical limitations, ergonomic design, and managing individual perceptual differences.

Keywords Multisensory integration · Audience engagement · Pressure stimulation · Immersion · Entertainment

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1 Introduction

Over the past century, film has evolved from silent black-and-white movies to talkies, color, 3D, IMAX, and 4Dx, with each innovation promising to enhance the audience's multisensory viewing experience. Yet the concept of adding tactile feedback to films, first mentioned in Aldous Huxley's *Brave New World* [1] as "Feelies", has never achieved commercial success. Our previous reviews explored the application of tactile feedback in film (a passive entertainment; see [2, 3]), gaming (an active entertainment; see [4]), and Virtual Reality (VR) [5], discussing challenges such as technological complexity, perspective-specificity, cognitive confusion, limited consumer demand, creative/ethical concerns, body sensitivity limitations, lack of interactivity, and limited evidence of enhanced immersion compared to its success in gaming.

Nonetheless, academic researchers, mainly in human-computer interaction (HCI), have continued to experiment with augmenting film with tactile feedback, hoping to enhance the audience's multisensory experience. However, as noted by Delazio et al. [6], most existing haptic interfaces for film and VR rely on vibrotactile stimulation alone, largely ignore sustained or distributed force feedback. Cross-modal correspondence theory [7], the effectiveness of multisensory integration depends critically on semantic alignment between sensory channels: when sensory features naturally "match" across the senses (e.g., visual expansion & tactile pressure), the brain processes them more fluently, thereby reducing cognitive load and enhancing immersion. In contrast, when modalities are semantically incongruent (e.g., visual inflation & vibration), cognitive dissonance may arise, undermining rather than enhancing the experience.

This study addresses this gap by introducing a novel approach: synchronized pressure feedback delivered through a full-body wearable bubble suit, tested in scenes where pressure is semantically congruent with the visual narrative of bodily inflation. To the best of our knowledge, pressure-based haptic feedback has not been explored in the context of augmented film experiences previously. The study aims not merely to ask, "Can pressure enhance film?" but more fundamentally, "Does matching the tactile modality to the narrative content matter?" and "Which tactile sub-modality best supports embodied narrative engagement in which contexts?" Additionally, this study assessed whether such multisensory enhancement affects the viewer's immersion, engagement, character identification, sense of realism, and willingness to pay (which is one of the important issues highlighted in our previous literature reviews; see [2, 3]) for the experience.

2 Related work

2.1 Commercial attempts to add tactile feedback in cinema

Adding tactile elements to cinema was first introduced in 1959 with the horror film *The Tingler*, where some seats were equipped with vibration devices [2, 8]. The audience's reactions varied: while some viewers, like John Waters, found this immersive experience memorable, noting that he enjoyed it, went to see it every day when he was young, and believed it taught him about art in cinema [9], others saw it as just a gimmick and criticized its cheap aesthetics [10]. The approach failed to spread, likely due to inconsistent implementation and associated costs [11].

In 1974, Universal Studios and Cerwin-Vega introduced “Sensurround,” using ultra-low-frequency sound waves to create physical sensations [12]. However, the technology was only used in a total of five films [13], primarily due to the high costs and limited compatibility of theatres [14]. Unsurprisingly, most early attempts at multisensory cinematic experiences, such as Sensurround, did not gain widespread popularity, remaining largely experimental.

Most recently, 4D cinema has revived haptic effects via motion-enabled seats and environmental cues. However, these effects are usually pre-programmed and often generic rather than narratively congruent. Critics have questioned whether these effects truly enhance immersion, or whether they are primarily gimmicks intended to increase novelty rather than narrative engagement [15].

2.2 Laboratory/artist attempts to integrate touch

Lemmens et al. [16] developed a wearable tactile jacket with 64 vibrotactile actuators designed to enhance a film's plots and increase emotional immersion for audiences. The jacket stimulated the torso and arms of participants with different levels of vibration, creating tactile patterns that correspond to different narrative elements. For example, a sensation described as ‘butterflies in the stomach’ represented love, while ‘shivering’ represented fear and anxiety, etc. The experiment outcomes ($N = 13$ participants) revealed promising effects on increasing immersion. However, the lack of counterbalancing (tactile feedback always delivered second) may have biased the results. Furthermore, while attempting some form of semantic connection (e.g., ‘butterflies’ for love), the system relies on vibration to communicate complex emotions, raising the question of whether this modality is truly congruent with the intended feeling, or just a symbolic gesture.

Mazzoni and Bryan-Kinns [17] developed a wearable glove that was designed to enhance mood music in films by delivering vibrotactile feedback to the user’s hand, one of the most sensitive parts of the body when it comes to the detection of vibration (see [18]). Building on Frith’s [19] idea that music in film can amplify what cannot be shown on screen, such as mood, the Mood Glove was equipped with eight vibe boards to create specific patterns of vibration corresponding to various emotional tones in the music. The study revealed that while the glove effectively heightened users’ arousal during film viewing, it did not significantly alter the valence of their emotional experiences. Additionally, the authors pointed out that the novelty of the experience and prior familiarity with the chosen film clips could be limitations, potentially restricting the generalizability of their findings beyond the specific context tested.

Ablart et al. [20, 21] used Ultrahaptics technology [22] to project mid-air haptics onto users’ hands during one-minute film clips, thus enabling multi-point mid-air haptic feedback for touch surfaces. The selected one-minute film clips already had a complete narrative, and the addition of mid-air haptic feedback significantly raised arousal levels during movie viewing, thus enhancing the intensity of the experience. However, it is important to note that arousal and immersion, while related, are distinct concepts. Immersion, unlike arousal, refers to the cognitive and emotional engagement in the content, leading to the sensation of being ‘in the moment’, while arousal is more closely tied to a more basic physiological response [23]. Furthermore, the study found that the haptics did not significantly affect emotional valence, likely because it lacked semantic congruence with the narrative content. The authors also noted that factors such as the novelty of the experience and people's familiarity with the films could diminish the observed effects.

The same haptic technology was also integrated in a public art installation at the Tate Britain, known as the Tate Sensorium ([24]; see also [25]). This multisensory art exhibition used mid-air haptics technology to deliver touchless tactile feedback, enhancing the emotional experience of viewing abstract art. Specifically, the haptic feedback was integrated with sound to augment the interpretation of the painting "Full Stop" by John Latham. While qualitative feedback suggested increased immersion, effects were not statistically tested. The study highlighted the tension between guided sensory input and individual interpretation.

Another non-direct contact art installation is SkinAir | Air Skin (2015) by Odysseas Klissouras, a multisensory experience that engaged both touch and hearing. The installation featured two auras: a silent one, where the participant could feel the tactile interactions of air pressure on their skin, and a noisy aura, where sound is generated by the air pressure adding an auditory track. Indeed, artistic practices have recently begun to show increased interest and attention to haptics, suggesting that haptic technology is becoming a more prominent and valued component in the field of artistic creation for both researchers and practitioners [26]. While vibrotactile and mid-air feedback have been explored, full body pressure-based sensations remain untested in the context of cinema. While vibrations are relatively easy to implement with current technology, they do not always provide a natural or emotionally resonant form of tactile stimulation. Furthermore, little is known about audiences' willingness to pay for such enhanced experiences. Such data will likely prove key to supporting any future implementation in a commercial setting.

To address these gaps in the literature, the study introduces a full-body wearable bubble suit that provides synchronized pressure feedback semantically aligned with the visual narrative of selected film clips. This research aims not only to explore the impact of pressure-based haptics on viewer immersion, engagement, and character identification but also to assess the audience's willingness to pay for such an enhanced cinematic experience.

3 Design and technical implementation

The bubble suit was originally developed by the second author, with programming and reorganization for the study conducted by the first author. It was initially designed for female models around 165 cm in height and weighing 55 kg. The bubble suit has been exhibited at multiple exhibitions including the 6th Art and Science International Exhibition and Symposium at China Communication Center for Science and Technology. Based on the previous feedback, the suit should deliver a noticeable sensation of pressure without discomfort.

Participants were required to first wear a smooth, black, tight-fitting bodysuit to reduce friction and sweating, which could otherwise affect comfort and pressure perception. Additionally, the air pump used for inflation was quite loud, participants wore noise-cancelling headphones to prevent auditory distraction during the film.

3.1 Materials

The Bubble Suit features a fully enclosed elastic garment structure that partially isolates the wearer from the external environment, enhancing immersion through synchronized pressure feedback triggered by visual stimuli. Constructed from soft, transparent and airtight PVC, the suit expands during inflation to produce a visual sense of expansion and a physical sensation of bodily compression. Its elasticity ensures comfort and shape recovery upon deflation.

To optimize the fit and sensory precision, the suit was tailored to closely follow human contours using a tight-fitting cut. Five bubble sizes (5 cm, 8 cm, 10 cm, 15 cm, and 25 cm) were strategically distributed across different body parts: "legs," "arms," "abdomen," "chest," "back," and "buttocks"- smaller bubbles for limbs and larger ones for the torso, back, and buttocks – ensuring both the aesthetic appeal of the garment and also guarantees that each bubble provides appropriate pressure and tactile feedback during inflation.

All bubbles are connected by silicone conduits, allowing air to freely transfer between the bubbles. Additionally, as shown in Fig. 1, this design enables us to more precisely control the bubbles in different parts of the body, as well as to control the release and circulation of air in individual bubbles in a timely manner, thereby enhancing the wearer's sense of immersion and the naturalness of the experience.

3.2 Selection of film clips

The first film clip was from *Harry Potter and the Prisoner of Azkaban* [27], in which Harry becomes angry and uses magic to blow up his Aunt Marge like a balloon (see Fig. 2). The second clip was from *Charlie and the Chocolate Factory* [28], where one of the characters (Violet) eats an imperfect chewing gum, causing her body to inflate into a large blueberry balloon (see Fig. 3). Both clips featured a common plot element whereby the main character's body gradually inflates.

3.3 Technical design

An Arduino-controlled air pump system was synchronized with specific film events. Each of the 20 bubbles inflated at different speeds (3-120 s), grouped into three sequences, with each group inflating over different intervals. However, since the bubbles were pre-inflated during the familiarization process and were not deflated completely between participants, the actual inflation time during the experiment was shorter. Additionally, during the process of putting on and taking off the suit, some air tubes occasionally became detached, and the bubbles could inadvertently be compressed, causing the air to escape. As a result, the amount of air in the bubbles and the actual pressure experienced by each participant may have varied somewhat. To prevent over-inflation and avoid damaging the suit, the inflation period was limited to 88s. For example, when a character's body inflates in the film, the bubbles on the suit begin inflating, providing the participant with pressure feedback, as if they themselves are inflating.

After the familiarization process, the bubbles were deflated and the participants were continuously asked whether they could still feel the pressure in the bubble suit. Once they reported that they could no longer feel any pressure, the deflation process was stopped.

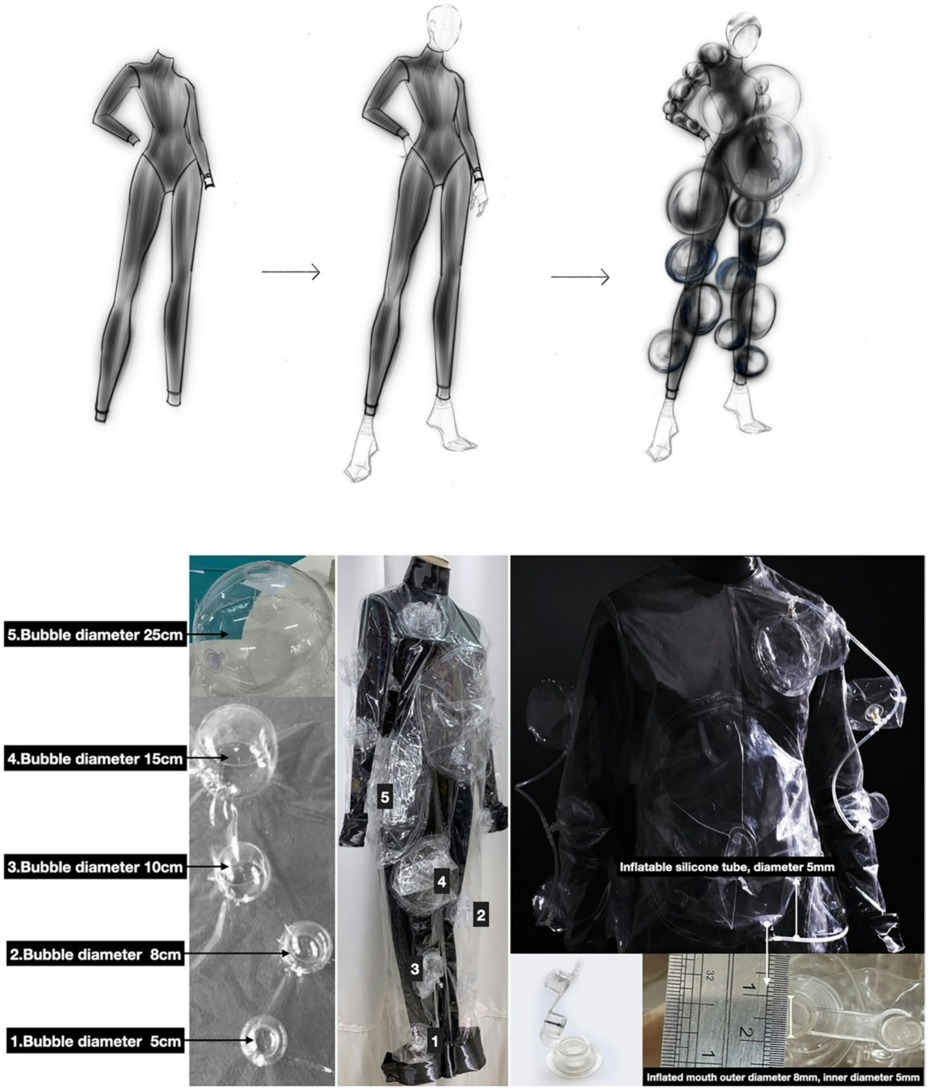

Fig. 1 Sketches for the bubble suit

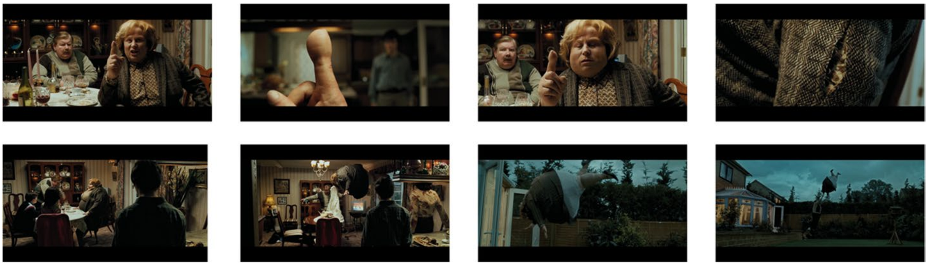

Fig. 2 Screenshots from *Harry Potter and the Prisoner of Azkaban* film clips

Fig. 3 Screenshots from *Charlie and the Chocolate Factory* film clips

Depending on the film they were assigned to receive pressure feedback, inflation began either at 75s into *Harry Potter* (when Aunt Marge begins to inflate) or at 35s into Charlie and the Chocolate Factory (when Violet begins to turn purple and inflate). In each case, the Arduino program was executed, gradually inflating the bubbles to ensure that the participants could start feeling the pressure as the program began.

4 Study

4.1 Participants

An a priori power analysis was conducted using G*Power version 3.1 [29] for sample size estimation. Based on a medium effect size (d = 0.5), a probability of 1 – β = 0.80, and an α-value of 0.05, a sample size of 34 participants was suggested for a two-tailed paired t-test.

For this experiment, 45 volunteers (5 males) were recruited. However, one female participant withdrew during the course of the experiment, and two participants had to be excluded due to technical issues and delays that occurred during the procedure, resulting in a final sample of 42 valid datasets. All participants were greeted by the researcher, completed an informed consent form, and were informed that the study was anonymous and that they could withdraw from the experiment at any time. Basic demographic information, such as gender, age, prior experience with haptic entertainment, and details of that experience (if applicable), was also collected.

4.2 Procedure

Step 1: Participants wore the bubble suit for about 5 min to familiarize themselves with the pressure (Fig. 4). They then described sensations or associations (e.g., “spaceman,” “astronaut,” “measuring blood pressure,” “space capsule,” “swimming,” “pregnancy,” “balloon,” “massage,” “being wrapped,” “hugged,” and others).

Step 2: Each participant stood while watching two different 2-minute film clips: one with pressure feedback, one without. Since all participants were from China, the official Chinese soundtrack and subtitles were used. The viewing order was counterbalanced: half saw *Harry Potter* first, and the other half *Charlie and the Chocolate Factory*. The pressure condition was also counterbalanced across participants.

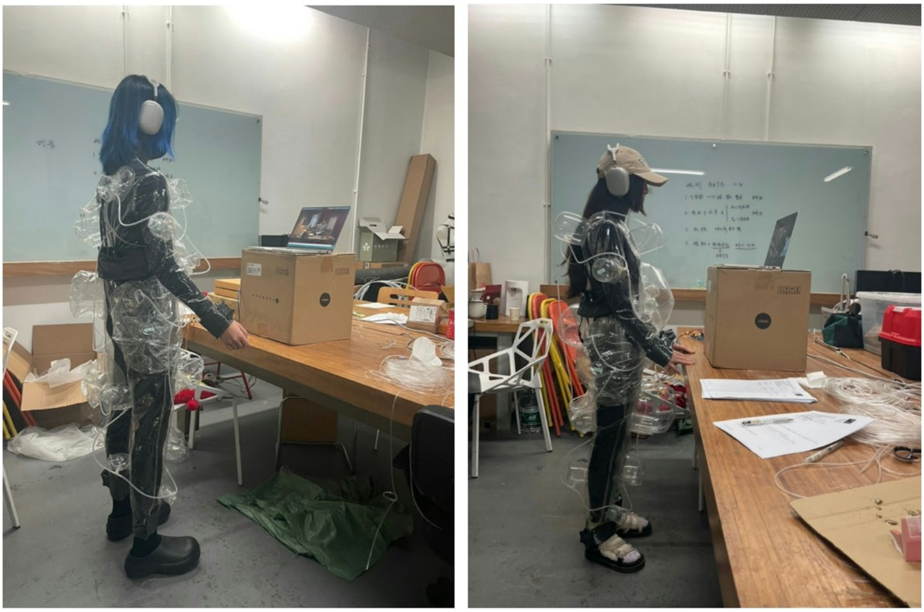

Fig. 4 Participant wearing the bubble suit during the study

Step 3: After each clip, participants completed a questionnaire on immersion, engagement, character identification with the characters, perceived realism, and willingness to pay for the entertainment experience. At the end, they gave open feedback and reported any discomfort. The entire session lasted approximately 30 min.

5 Results

5.1 Main effects of haptic feedback on narrative experience

Since the data did not meet the assumption of normality (as assessed by Shapiro-Wilk tests), non-parametric Wilcoxon signed-rank tests were used to compare participants' ratings between the pressure and no-pressure conditions. Bonferroni corrections were applied to control for Type I errors arising from the multiple comparisons across the seven dependent variables (adjusted $\alpha = 0.05/7 \approx 0.007$). Effect sizes (rank-biserial correlation r and Cohen's d) and 95% confidence intervals (CIs) were also reported to indicate the magnitude and precision of each effect. Pressure feedback significantly enhanced participants' scores across multiple dimensions, including immersion (Q1), narrative engagement (Q2, Q3), attention/focus (Q5), realism (Q8), and willingness to pay (Q9). However, for Q4 (which asked whether changes in the film plot affected participants' emotions; $p = 0.175$), the effect of pressure feedback was not significant. The descriptive statistics and significance levels are

Table 1 Summary of Wilcoxon signed-rank results: means (± SD), Z, Bonferroni-adjusted p (p_adj), effect sizes (r, d), and 95% CI under no-pressure and pressure conditions

Measure	No Pressure (M ± SD)	With Pressure (M ± SD)	Z	p	p_adj	Effect size®	Cohen's d	95% CI
Q1	2.86 ± 0.87	3.43 ± 0.86	-2.92	0.003	0.028	0.45	0.66	[0.50, 1.50]
Q2	3.55 ± 0.92	4.00 ± 0.66	-2.83	0.005	0.037	0.44	0.56	[0.00, 1.00]
Q3	3.62 ± 0.79	4.12 ± 0.67	-2.95	0.003	0.026	0.46	0.68	[1.00, 1.50]
Q4	3.57 ± 0.77	3.76 ± 0.85	-1.36	0.175	1	0.21	0.24	[0.00, 1.00]
Q5	3.37 ± 1.07	4.13 ± 0.63	-4.3	<.001	<.001	0.66	0.82	[1.00, 1.50]
Q8	2.10 ± 1.08	3.37 ± 1.07	-4.67	<.001	<.001	0.72	1.19	[1.50, 2.00]
Q9	20.21 ± 23.55	40.89 ± 28.11	-5.09	<.001	<.001	0.79	0.88	[19.00, 30.00]

summarized in Table 1, which includes means (± SD), Z values, adjusted p-values, effect sizes, and 95% confidence intervals.

Willingness to pay (Q9) showed the largest increase in magnitude and the largest effect size among all measures, with participants reporting a 102.3% higher average willingness to pay under the pressure condition (an 20.68 RMB increase, 95% CI [19.00, 30.00]). Notably, among those participants who reported zero willingness to pay in the no-pressure condition ($n = 14$), the increase was treated as 100%. When accounting for these cases, the average individual percentage increase reached 187.6%.

All significant results remained significant after Bonferroni adjustment, supporting the robustness of the observed pressure effects across subjective experience dimensions.

5.2 Effect of haptic feedback on role empathy

To explore whether pressure feedback influenced the choice of empathized characters (Q6) and empathy intensity (Q7) within the same film, responses from each film clip were analyzed separately. In the Harry Potter condition, the distribution of selected characters significantly differed between the pressure and no-pressure groups ($\chi^2 = 9.00$, $p = 0.011$). Notably, participants under the pressure condition were more likely to empathize with the "Aunt" character, whereas the majority in the no-pressure condition chose "Harry Potter" instead. Although empathy scores (Q7) were higher under pressure (M = 3.50 ± 0.24) than under no-pressure (M = 2.95 ± 0.24), the difference did not reach significance ($p = 0.070$, $r = 0.42$, 95% CI [0,1]), though a medium effect size was observed. In contrast, for the Chocolate Factory condition, neither the distribution of empathized characters ($\chi^2 = 0.00$, $p = 1.000$), nor the empathy scores (M = 3.58 ± 0.25 vs. M = 3.11 ± 0.27, $p = 0.179$, $r = 0.22$), significantly differed between the pressure and no-pressure groups. In total, 78 valid responses were included in the analysis (after excluding 6 participants with missing Q6 or Q7 data), with 41 participants watching the Harry Potter clip and 37 watching the Chocolate Factory clip. This suggests that haptic feedback may shift a viewer's attention or emotional salience to specific characters – a phenomenon conceptually similar to how musical soundtracks shape the interpretation of audiovisual content, including empathy toward the characters [30–32].

To further examine whether pressure feedback modulated empathy intensity within participants, a within-subject analysis was conducted including 36 participants who completed both conditions with valid Q7 responses. A Wilcoxon signed-rank test revealed that empathy scores were significantly higher under pressure (M = 3.72 ± 0.16) than in the no-pressure condition ($M=3.08\pm0.17$), $p=0.0018$, $r=0.52$, 95% CI [0.50,1.50]. These results suggest a robust within-participant enhancement of emotional engagement under haptic feedback.

5.3 Influence of film type, view order, and participant's previous experiences

Exploratory analyses were conducted to examine whether film type (Harry Potter vs. Chocolate Factory), view order (first vs. second), or prior experience with haptic entertainment influenced participants' responses across the key measures (Q1–Q5, Q8, Q9). None of the factors yielded significant effects (all $p>0.08$, Bonferroni-adjusted $p=1.00$, $\eta^2_p < 0.07$). These results suggest that the observed differences between pressure and no-pressure conditions were not attributable to the film content selected, viewing order or participants' prior haptic experience.

5.4 Perceived effectiveness of haptic feedback

Perceptions of the pressure feedback were also evaluated through three additional questions (hQ1-hQ3), which assessed whether participants felt that the haptic feedback enhanced realism (hQ1), made scenes more vivid and interactive (hQ2), and felt natural (hQ3). Across all three items, participants' ratings were significantly above the neutral midpoint of 3, indicating a generally positive reception of the tactile experience. Participants reported particularly high agreement that haptic feedback enhanced realism (hQ1: $M=4.15\pm0.10$, $p<0.0001$), improved vividness and interactivity (hQ2: $M=3.90\pm0.10$, $p<0.0001$), and felt natural within the film experience (hQ3: $M=3.80\pm0.11$, $p<0.0001$).

5.5 Audience feedback

Many participants described the experience as "novel," "magical," "being in the film," "could feel the character's emotions and actions," or "felt like they could fly as well,". At the same time, however, they also mentioned some disadvantages. For instance, they found it difficult or felt that it required effort to wear, and expressed that they probably wouldn't want to wear it in a cinema due to the hassle. They also noted that the suit was very tight and not breathable, which could make it uncomfortable. Some suggested that while a wind-blowing device might be acceptable, the wearable suit was not very comfortable. Additionally, they wished for more tactile experiences, such as the sensation of being hit, to enhance the entertainment experience further.

6 Discussion

6.1 Suit design and participant variability

The first and most significant issue concerns the customization of the wearable device. This particular suit, like many wearables, is designed for a specific body type, which presents challenges given that participants have varying heights and body shapes. In fact, a couple of potential participants had to be excluded due to the fact that the suit did not fit them. This issue also led to varied experiences amongst the participants. Those with body types similar to the female model that the suit had been designed for had a better experience, as the suit fit them perfectly. A more flexible or modular design could potentially be designed to enhance comfort and ensure consistent pressure across different body types. Conversely, those participants who were too thin faced the problem of the pressure being less noticeable, causing the tactile simulation and audio-visual content to be desynchronized. Two participants even reported not feeling any feedback at all during the film, despite the bubbles being fully inflated. In addition, individual differences in tactile sensitivity and attention may also have contributed to variability in perceived pressure across participants. However, this might also be due to visual dominance or the phenomenon of tactile inattentional blindness (see [18, 33]). Several participants mentioned feeling the pressure during the familiarization step but failed to notice it during the actual film clips, possibly due to the fact that their attention was more focused on the visual aspects of the film. Additionally, as participants were required to stand throughout the experience, this setup was more appropriate for short entertainment experiences rather than full-length features.

Furthermore, participants' experience of the pressure feedback varied, with some describing the experience as immersive and "magical" and others feeling that the pressure was too subtle or inconsistent. These differences suggest that both physiological factors (e.g., body shape, clothing fit) and psychological expectations (e.g., prior exposure to multisensory media) play important roles in shaping haptic perception.

6.2 Practical challenges in using wearable devices

Public use of wearable suits raises hygiene concerns. One or two of the participants explicitly raised concerns about hygiene, and a few others appeared slightly hesitant, although this was not directly expressed to the experimenter. After the experimental procedure was explained and the participants were reassured that they could withdraw from the study at any time, they all decided to continue voluntarily. Since the suit requires a tight-fitting bodysuit, participants needed to change clothes, which would be impractical in cinemas.

Additionally, there are issues with comfort. Several participants noted that the suit was airtight, and one found the inner black bodysuit to be somewhat itchy. To achieve full-body pressure, bubbles were attached to the back, glutes, and the back of the thighs, meaning participants could only watch the film while standing. While this might be acceptable for a 2-minute film clip, it's easy to see how watching a 2-hour film in this manner would likely be uncomfortable and tiring. Additionally, the experiment was conducted during the summer in Beijing, with outdoor temperatures of around 35 °C. The air conditioning was set to 18 °C to prevent participants from feeling hot and sweaty. At the same time, however, given that the suit is very thin, it might also be unsuitable for winter conditions, if the ambient temperature were to drop too much. The suit is currently both expensive and technically complex. The bubble suit itself costs around 3000 RMB (approximately £318 Sterling) and, as highlighted already, only fits a specific range of body types/sizes.

Some participants described the suit as "claustrophobic," "too tight," or "inconvenient for sitting," suggesting the need for improved ergonomics and breathability. Some wanted to try the suit while seated or watching a longer film. Another observation related to the film is that, unlike visual or audio tracks, a tactile feedback "track" may not inherently convey meaning. This was evident during the word association task, where about half of the participants could not associate the pressure with any specific word or scenario. However, when combined with the audiovisual feedback, they understood why the tactile feedback was present.

In addition, a number of the participants highlighted a mismatch between the visual narrative (characters inflating like balloons) and the physical sensation (being compressed or hugged). This perceptual dissonance suggests a challenge in semantic mapping: the tactile sensation may need to more accurately reflect the metaphor or emotional logic of the scene rather than its literal action. In future designs, pressure might be more effectively used to simulate feelings of tension, suffocation, or emotional intensity, rather than simply mimicking visual inflation. This highlights the importance of improving narrative-to-haptic mapping in order to achieve greater coherence and emotional resonance.

Another limitation of the current study is that the pressure exerted by the suit on participants was not measured, which may have led to variations in the perceived pressure across participants of different body types. Incorporating pressure sensors in future designs would allow for more accurate calibration and provide further insight into how tactile intensity interacts with user perception and immersion. During the familiarization process, the bubbles were inflated to allow participants to feel the pressure, and then deflated. However, by the time the experiment started, the volume of air inside the bubbles varied between participants. In some cases, because the air volume was already quite high, it took less than 88 s for certain groups of bubbles to become fully inflated. To prevent over-inflation, the air pump's wire on the Arduino breadboard was manually unplugged, meaning that for those participants, the pressure did not gradually increase but was instead already at its maximum. While the inflation started simultaneously for all participants, the actual pressure they experienced may have differed due to the varying inflation times for different bubbles and differences in body shape.

6.3 Limitations in data collection

While the core narrative and experience questions (Q1-Q5, Q8, Q9) were fully completed by all participants, a small number of responses were missing in the empathy-related questions (Q6: 7 missing; Q7: 6 missing), potentially impacting the reliability. Some missing responses may also reflect a lack of strong empathic preference toward any specific character, which can naturally occur in film-viewing scenarios. Future studies could improve completion rates by refining question design and enhance the statistical robustness by increasing sample size.

Additionally, participants' open-ended comments suggest that empathy and character identification may be influenced not only by the presence of haptic feedback, but also by the perspective the haptic supports. Some viewers reported shifting their empathy from the main character (e.g., Harry) to the inflating side characters (e.g., Aunt Marge) when pressure was applied. This points to the possibility that tactile feedback can reframe narrative focus and redirect emotional engagement.

Another limitation concerns the demographic composition of the sample. All participants were recruited from China, and most were female, which may limit the generalizability of the findings. In future studies, we intend to recruit a broader and more diverse sample of participants to examine potential cultural or gender differences in haptic cinematic experiences, although there are no a priori reasons to expect that this would make a difference.

6.4 Influence of tactile feedback on realism and engagement

The significant main effect on realism (Q8) highlights the potential of tactile feedback to enhance the perceived authenticity of the experience. This finding aligns with the theories of embodied cognition, which suggest that physical sensations strengthen psychological immersion and realism. Moreover, the interaction between tactile feedback and film type suggests that the effectiveness of haptic feedback may depend on a movie's narrative or sensory design. Future studies should therefore investigate how specific genres and scene types interact with tactile feedback to shape the perception of realism.

While the main effect of viewing order was not significant, significant Film × Order interactions were observed for engagement (Q5) and willingness to pay (Q9). This suggests that the sequence in which participants viewed the films influenced their responses, possibly due to novelty effects or heightened attention during the first viewing. Future research could further explore how viewing order moderates the impact of tactile feedback on audience responses.

6.5 Practical implications and future directions

As the study used only two film clips with similar "inflation" themes to isolate the pressure effect, future research should explore a wider range of cinematic contexts and genres (e.g., action, drama, horror) to assess the generalizability of the findings. For future iterations, it would be beneficial to implement a system with dual channels for inflation and air intake to ensure consistent air pressure across all bubbles. Additionally, ensuring that the initial air volume in the bubbles is standardized for each participant would obviously improve consistency. It is also important to ensure that the air tubes do not become detached during the process of putting on and removing the suit, as this could impact the pressure consistency. The issue of bubbles being inadvertently compressed during the process of putting on and taking off the suit, leading to variations in the internal air volume, also needs to be addressed in the future designs to improve the reliability of the tactile feedback. Furthermore, participants expressed a desire for more diverse tactile sensations – such as impact, shivering, or heat – instead of a single form of pressure. While the bubble suit serves primarily as a proof-of-concept and artistic exploration, future iterations should investigate more cinema-ready implementations, such as pressure-embedded seating or standardized wearable modules to assess scalability for more realistic cinematic contexts. Future research could also explore multisensory integration (e.g., combining pressure with vibration, heat or airflow) and assess long-duration comfort and feasibility for public cinema settings.

In conclusion, this study presents the first investigation into the impact of pressure on people's enjoyment of short film clips. Given the positive results, there is clearly grounds for further research comparing different forms of vibrotactile stimulation in order to see whether specific kinds of tactile stimulation are more appropriate for specific situations.

Abbreviations

HCI Human-Computer Interaction
WTP Willingness to pay
VR Virtual reality

Authors' contributions Yang Gao: Conceptualization, Methodology, Software, Hardware, Validation, Formal analysis, Investigation, Writing – Original Draft, Writing – Review & Editing.
Guiyu Liu: Hardware, Validation, Formal analysis, Investigation, Writing – Original Draft, Writing – Review & Editing.
Charles Spence: Conceptualization, Methodology, Writing – Original Draft, Writing – Review & Editing, Supervision.
All authors read and approved the final manuscript.

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Data availability The data and materials that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval The study was approved by the Central University Research Ethics Committee of University of Oxford [R94227/RE001].

Consent to participate All participants provided written informed consent before taking part in the study.

Consent to publish All participants gave explicit consent for their anonymized data to be published as part of this research.

Competing interests The author declares no competing interests.

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