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Review

Enhancing Presence, Immersion, and Interaction in Multisensory Experiences Through Touch and Haptic Feedback

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Abstract: In this narrative historical review, we take a closer look at the role of tactile/haptic stimulation in enhancing people's immersion (and sense of presence) in a variety of entertainment experiences, including virtual reality (VR). An important distinction is highlighted between those situations in which digital tactile stimulation and/or haptic feedback are delivered to those (i.e., users/audience members) who passively experience the stimulation and those cases, including VR, where the user actively controls some aspects of the tactile stimulation/haptic feedback that they happen to be experiencing. A further distinction is drawn between visual and/or auditory VR, where some form of tactile/haptic stimulation is added, and what might be classed as genuinely haptic VR, where the active user/player experiences tactile/haptic stimulation that is effortlessly interpreted in terms of the objects and actions in the virtual world. We review the experimental evidence that has assessed the impact of adding a tactile/haptic element to entertainment experiences, including those in VR. Finally, we highlight some of the key challenges to the growth of haptic VR in the context of multisensory entertainment experiences: these include those of a technical, financial, psychological (namely, the fact that tactile/haptic stimulation often needs to be interpreted and can reduce the sense of immersion in many situations), psycho-physiological (such as sensory overload or fatigue), physiological (e.g., relating to the large surface area of the skin that can potentially be stimulated), and creative/artistic nature.

Keywords: virtual reality; haptic VR; touch; haptics; tactile feedback; multisensory; entertainment technology

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1. Introduction

1.1. Defining Virtual Reality (VR) and Its Core Components

Burdea and Coiffet [1] characterize virtual reality (VR) as having three core components: immersion, interaction, and imagination. Immersion, involving "sensory immersion", refers to those situations in which people find themselves in a multisensory environment in a virtual setting [2]. Unlike the tradition of film, where the audience merely observes the predetermined storyline (that is, they watch passively), VR typically allows the audience to participate actively and potentially even dynamically influence the events and experiences as they unfold. Interaction is important in that it is part of what differentiates VR from other media by giving users active control over some aspects of the experience, thus allowing them to navigate virtual worlds and manipulate virtual objects in a user-guided manner, creating a unique and highly personalized experience. This is especially important in the context of telepresence applications [3]. Gao and Spence [4] (Spence and Gao [5,6]) highlight an important distinction between active and passive forms of entertainment in several of their recent reviews, and so this topic will not be covered in any detail here.

Writing a few years earlier, Steuer [3] highlighted the importance of understanding VR not merely as a set of technologies but as a human experience, with presence being a key component in the latter. Presence, referring to the sensation of being in a mediated environment, is undoubtedly crucial as far as creating immersive (according to Constantin and Grigorovici [7], while immersion refers to the objective technological features that help to engage or absorb users in a virtual environment, presence refers to the user's subjective feeling of actually being in that environment) experiences in VR is concerned. According to Gallace and Spence [8], tactile stimulation can, at least in the best-case scenario, make virtual objects and experiences feel more realistic by enhancing the user's sense of presence and physical engagement. As such, it might have been expected that tactile stimulation would, and potentially should, play a more significant role in VR than it currently does. In this review, we take a closer look at a number of the factors that may have limited the uptake of tactile/haptic VR.

1.2. The Role of Haptic Feedback in VR

In this narrative historical review (see [9,10]), the focus is on how haptic feedback enhances the immersiveness of entertainment experiences, including those involving VR, particularly through its active element. The role of haptic stimulation across various forms of entertainment is examined: This includes examples of passive storytelling (multisensory experiences) (The term "passive storytelling" is used here to describe those experiences where the user's engagement is focused on interacting with a pre-programmed environment, often involving tactile (rather than haptic) stimulation. In such cases, while the narrative and environment are fixed, users still actively engage with tactile and other forms of sensory feedback, which enhances the user's/audience's immersion, but does not alter the pre-programed storyline or world. In contrast, haptic feedback (involving active touch) is more likely to be associated with active storytelling, where the user's interactions may influence the narrative or environment), interactive (i.e., active) storytelling, and gaming. We also highlight the various ways in which haptic feedback may enhance (or detract from) immersive VR experiences, particularly given the latter's active features. Historically, VR has tended to focus primarily on visual and, subsequently, also auditory stimulation. While early research on the integration of haptic elements into entertainment experiences, including those involving VR, would still appear to be in its infancy (see [11–13]), recent advances in wearable systems—particularly soft actuated interfaces and electrohydraulic technologies—have enabled more immersive and nuanced haptic feedback, enhancing user interaction in virtual environments [14], thus creating new possibilities for haptic entertainment. Research also shows that multisensory experiences in AR/VR lead to higher visual appeal, emotional appeal, and increased purchase intentions [15].

The ubiquitous emphasis on vision in the delivery of entertainment experiences, including those in VR, makes sense due, in part, to vision's seemingly unique status amongst the senses [16]. It has been argued that vision has a much higher information processing bandwidth than the other senses, thus allowing for vast amounts of information to be conveyed quickly (see [11,17]). Nevertheless, while vision may well be the dominant sense (at least in terms of its bandwidth for information processing in humans), haptic feedback has been argued to play a complementary role, potentially enhancing the overall sense of presence and immersion, similar to the way in which sound complements visuals in cinema. Given the central importance of immersion and presence to VR experiences, a key question concerns which sense(s), either in isolation or in combination with other senses, helps to give rise to the most immersive experiences where the sense of presence is optimized.

Haptic VR (as opposed to touch-augmented VR) involves more than just receiving tactile sensations from a device. It necessitates a responsive interaction process that evolves over time as a function of the user's engagement, making the latter feel as though they are actually physically interacting with the digital world. In other words, and importantly in the context of the present review, not all tactile feedback necessarily qualifies as "haptic VR". At the same time, however, not all tactile feedback should necessarily be classified as "haptic" either, at least not in the sense that the term is used by experimental psychologists and psychophysicists (who use the term specifically to refer to active touch).

1.3. Types of Tactile Feedback in VR

Tactile feedback can be categorized into three main types: passive (e.g., vibration), interactive (e.g., force feedback), and active exploration (genuine haptic feedback). It is important to recognize how each type of tactile feedback may contribute somewhat differently to the user's experience in VR (separately, other researchers have distinguished between passive, active, and intra-active (self) touch [18]). In this review, those VR experiences that incorporate pre-programmed, passive tactile feedback (meaning that it is not interactive because it does not dynamically respond to user input) are discussed. However, it is important to distinguish such passive experiences from, say, those that were delivered during the movie *Earthquake* using Sensurround technology. There, vibrations were transmitted through the structure of the theatre itself using low-frequency speakers (see [5], for discussion). In the case of passive VR experiences, users can still engage with the virtual world through their head movements, giving rise to predictable changes in perspective. There may also be limited forms of interaction, such as virtual characters returning the user's gaze when looked at [19]. Although such interactions do not necessarily actively alter the virtual environment itself, they can nevertheless dynamically adjust how the virtual world is presented to (and thus experienced by) the user in real time. In traditional entertainment media, such as, for example, cinema, where the members of the audience can obviously move their eyes and/or head, such actions merely affect which part of the screen is visible and where the audience member's overt visual attention happens to be directed (that is, they do not change the viewpoint from which the action is experienced). By contrast, in VR, such actions also influence the user's perception of space, that is, they may change the user's perspective and field of view within the virtual environment, thus making the experience responsive to the user's physical actions.

To systematize the various tactile types and provide a clearer understanding of their characteristics, Table 1 summarizes the different tactile interaction parameters and their categories based on the technologies and studies in this article.

Table 1. Classification of Tactile Interaction Parameters.

Parameter	Category
Feedback Type	Vibration, Force Feedback, Ambient Tactile Cues, Mid-Air Haptics, Electrotactile Feedback
Interaction Type	Active Touch, Passive Touch
Perception Type	Direct, Inferential
Coverage Area	Localized, Full Body
Touch Location Relevance	Relevant and Varies, Fixed and Irrelevant
Temporal Nature	Continuous, Discrete

1.4. Haptic VR and Embodiment

In contrast, passive tactile stimulation, where the user passively receives vibrations or sensations, might not fully qualify as "haptic VR". However, if the user can choose to interact with objects, for example, by picking them up in order to feel their texture, this interactive element not only changes the nature of the tactile/haptic experience but also, in some sense, transforms the user's perspective and engagement with the virtual environment, thus presumably qualifying as a genuinely haptic VR experience.

Haptic feedback in the context of the discussion presented here typically refers to digitally mediated sensations that are delivered via devices such as controllers, gloves, or suits that are equipped with sensors that are capable of detecting certain of a user's movements and/or gestures. At the same time, actuators deliver physical sensations when users interact with the virtual environment in a particular way or when they interact with specific virtual objects. These systems are capable of simulating a range of tactile sensations including everything from simple vibrotactile stimulation (e.g., as found in many games consoles) through to more complex sensations such as temperature, wind, and even force feedback, thus potentially offering users more lifelike and immersive experiences as a result of their replicating a broader spectrum of physical (i.e., bodily) sensations.

In visual and auditory VR, the focus is typically on what is happening in extrapersonal space, given that what is simulated are distal objects and environments [20,21]. By contrast, haptic VR is closely tied to the user's bodily experiences and their sense of physical presence. Furthermore, the source object or event in the virtual environment that gives rise to the tactile/haptic stimulation is typically situated in the user's peripersonal space. By delivering tactile stimulation directly to the skin's surface, haptic VR can potentially promote a stronger sense of embodiment, thus adding to the user's feeling of being physically "inside" the virtual world. The close link between direct digitally controlled tactile stimulation of the body and embodiment means that haptic VR can deliver a uniquely immersive sensory experience. The fact that tactile feedback is directly felt on the user's skin can thus help to create a more personal/intimate connection to the virtual world, unlike visual or auditory stimuli, which are typically associated with extrapersonal stimuli and events. Here, it is also worth noting how touch (especially interpersonal touch; see [22], for a review) is closely tied to emotional responses and bodily awareness, thus again meaning that haptic VR experiences can feel much more intimate. (At the same time, however, it is important to note that, especially if the referent/meaning of the tactile stimulation in the virtual environment has to be inferred (e.g., as is the case of tactile warning signals and alerts), there is a danger that the user's attention will end up being focused in the space of their own body (figuring out "what is this I feel on my body/skin?"), rather than on what is happing "out there" in peripersonal or extrapersonal space (e.g., see [20,23])).

As Steele [24] noted recently, haptic feedback can deepen emotional connections by allowing people to believe that they are physically feeling objects and, on occasion, experiencing the expected consequences of their actions. This can potentially add to the realism, emotional engagement, presence, and immersion of a simulated experience. Unlike VR experiences with added tactile/haptic elements, and where the tactile feedback can be seen as nothing more than merely an "add-on" element, in haptic VR, active touch is integral to the overall multisensory experience. In the case of haptic VR, tactile/haptic feedback does not merely enhance immersion or realism but can be seen as representing a core element of the experience, enabling users to feel physically present within the virtual environment. Crucially, this feedback dynamically responds to the user's movements and interactions within the virtual space.

1.5. Realism and Interpretation in Haptic VR

Importantly, this does not necessarily require that the user exactly replicate the posture or movements of the virtual character (although doing so may enhance the experience; see [25]). Instead, the tactile feedback is designed to align with the detected user input and the system's responses, thus creating a sense of embodiment without necessarily demanding precise physical alignment between the user's bodily movements and those of the virtual character.

Ideally, users engaged with haptic VR should not have to interpret the tactile feedback, such as vibrations, as symbolizing something else (e.g., as in the case of the vibrations typically delivered by a computer game console to the gamer's hands, say, which might be intended to indicate an event or action that is occurring within the game environment, such as being hit or one's player having "low health"; see Gao and Spence, submitted). Although the objects or experiences that are represented by haptic feedback in VR are simulated and not real, the tactile sensations themselves can nevertheless still sometimes create a convincing sense of realism. For example, the vibrations experienced during an on-screen earthquake—as in the "Sensurround" technology that was used in the 1974 film *Earthquake* [26]—can be used to help replicate (or simulate) the tremors that would be associated with an actual earthquake (thus potentially helping to break the "fourth wall" between audience and on-screen action (see [5,6])). When combined with other cues, such as auditory and visual stimuli, this multisensory stimulation will often help to clarify the context in which tactile stimulation is taking place, hence disambiguating the meaning (or referent) of the latter. This may help to enhance the immersiveness of the experience.

1.6. Challenges in Implementing Haptic VR

Even when the user realizes that the tactile feedback and other sensory cues, such as any digital auditory and visual stimuli, have been generated artificially, such as was presumably the case in the simulation of an earthquake in the movie *Earthquake*, the combined effects can still potentially strengthen the sense of realism (and immersion). This allows the user to experience the virtual environment not only through their eyes and ears but also through their skin (and body); they are able to interact with the virtual environment via their bodily movements, thus engaging proprioception (the feeling of where the parts of the body are in relation to each other) and kinesthesis (the feeling of the body's movement through space).

While purely visual or auditory cues can elicit certain bodily sensations (such as in the case of the sound-induced autonomous sensory meridian response (ASMR); e.g., [27]), haptic VR is importantly different. The latter requires the direct physical stimulation of the skin surface by means of haptic devices, such as those that are capable of delivering some form of vibration or force feedback. While ASMR can elicit bodily sensations as a result of specific, typically auditory, triggers, haptic VR directly engages the sense of touch in a more immediate and physical way by directly stimulating the skin, providing a physically interactive layer to the virtual experience. However, unlike the technologies that support visual and auditory VR, which can effectively occupy (and so stimulate) the entirety of the visual and auditory field, respectively, the sense of touch covers a much larger surface area—namely, the entirety of the skin's surface (accounting for 16–18% of body mass [8,28]). As Daniel Dennett [29] noted several decades ago, it is obviously going to be extremely technically challenging to provide digitally controlled tactile/haptic feedback across the entire body surface at once [30]. What this means in practice is that, thus far, systems for digitally stimulating the skin typically only ever target (and thus stimulate) a relatively small area of the user's total skin surface. It is to be expected that such a limitation in terms of tactile stimulation ought to deleteriously affect the degree of immersion, as users are obviously only receiving very limited tactile feedback as compared to what might be expected were their full body to be stimulated.

Adding tactile feedback in VR systems has sometimes been reported to enhance the immersive experience [31], thus potentially creating a more believable and immersive environment [32–34]. While such suggestions are promising, they raise a number of important issues about the broader implications of multisensory integration in VR. For instance, enhancing one sensory modality, such as touch, also indirectly influences the perceived realism of the experience delivered by the other senses, such as vision or audition. Despite this potential for cross-sensory (or crossmodal) influence or multisensory integration (see [35,36]), the practical implementation of tactile feedback technologies remains limited due to technical and cost-related challenges, which will be explored in more detail below.

One might therefore wonder whether, in the case of haptic VR, only the stimulated part of the user's body actually feels as though it is part of the virtual environment. Fortunately, however, such a disjointed and partial experience would appear not to be the case. This is presumably because the stimulation of specific areas of the skin surface leads to a person's attention being captured by (and thus directed towards) those parts of the body that are stimulated [37–39]. This may help to make even limited tactile feedback feel particularly immediate and immersive [8]. Indeed, it is worth considering how those areas of the skin surface that receive relatively constant tactile stimulation, such as, for example, those sensations associated with the feeling of the clothes on our body, are typically not part of our conscious tactile/bodily experience, other than when we specifically direct our attention to them (as may just have happened to you on reading the last sentence). As such, this localized attentional focus on dynamic tactile stimuli can still enhance the feeling of being physically present in the virtual world, even though only a small part of the skin is actively stimulated by technology.

1.7. Perceptual Completion

While many VR experiences require the user to engage physically with the virtual environment by means of their own bodily movements and actions, such experiences are sometimes combined with various wearable devices. Thus, even though current haptic systems typically only stimulate a small portion of the user's skin surface, this localized feedback is often sufficient to create a strong sense of immersion and presence in a virtual environment [40]. A relevant analogy can be drawn here with visual perception in the context of digital rendering in VR. Just as it is computationally expensive (and time-consuming) to render the entire visual field in high definition, designers typically render only the central visual field in sufficient detail, leaving the periphery blurry and trusting that users will simply remain unaware of the lower resolution in the periphery of the visual field (see [41] for a review). Similarly, while the skin covers a large surface area, the focus of our tactile attention is usually limited to those specific parts of the body that we are currently using to interact with the world around us. Indeed, in many such cases, much of our tactile experience is seemingly "filled-in" by the brain [4], in much the same way that the blind spot in vision is automatically completed [42,43].

The existence of such constraints (on attention) in the tactile information-processing system, together with the possible perceptual (specifically tactile or bodily) filling-in that may take place, means that designers might only need to stimulate localized areas of the skin in haptic VR, safe in the knowledge that users will still feel a convincing sense of physical presence (and remain unaware of those unstimulated parts of the body surface because they are simply not attended to). Indeed, there is an extensive body of research demonstrating the existence of the phenomenon of tactile change blindness (e.g., see [44]), namely a lack of awareness of significant changes in the pattern of tactile stimulation across the body surface (see also [45]). An extensive body of laboratory research further demonstrates that when people are concentrating on visual stimulation, such tactile inattentional blindness can be even more noticeable (e.g., [46]).

1.8. Haptic Feedback and Multisensory Immersion

The integration of haptic feedback into VR not only potentially enhances the user experience but also introduces an interesting question about what constitutes "virtual reality" in the context of touch/haptic stimulation. VR has traditionally focused on visual and to a lesser extent, auditory experiences (see [47], for a review of the latter). While the addition of haptic feedback delivers physical sensations, similar to how visual and auditory sensations are created, in all three cases, the objects and events that are typically expected to give rise to those sensations are not actually present. This illusion blurs the line between the virtual and the physical, enhancing immersion and allowing users to engage more deeply with virtual environments through multisensory experiences.

The phenomenon of multisensory Integration leads to the following consideration: is there a virtuality–reality continuum in haptic VR (cf. [48]), whereby digital touch can enhance the sense of realism of virtual environments and events? This question remains open to further exploration/research. By engaging multiple senses, particularly in the case of haptic feedback, VR can help to push the boundaries of immersive experiences. However, achieving the level of multisensory integration that is required to deliver on this promise comes with technological, psychological, and conceptual challenges. In the following sections, we will first explore the role of haptic feedback in enhancing presence and immersion in VR and then trace the historical development of haptic technologies in immersive entertainment, before examining the challenges and limitations that continue to shape the future of haptic innovations in VR.

2. The Role of Tactile Stimulation, Including Haptic Feedback, in Enhancing Presence and Immersion in Experience

While Section 1 focused on tactile/haptic feedback specifically within VR environments, it is important to recognize that adding haptic stimulation plays a significant role in enhancing presence and immersion across a variety of entertainment experiences, regardless of whether they are technically considered VR or not. In the sections that follow, we explore the broader application of tactile feedback in the design of immersive experiences.

2.1. Types of Tactile Feedback in Immersive Experience: Vibration, Force Feedback, Wind, Heat, Mid-Air Haptics, and Electrotactile Feedback

2.1.1. Vibration

One of the first examples where touch was deliberately added to enhance the audience's enjoyment of (and presumably their immersion in) entertainment was in select screenings of the movie *Earthquake* in the 1970s. In this case, Sensurround technology was used in a small number of cinemas in order to simulate the sensation of an earthquake by means of powerful infra-bass sound waves, creating low-frequency vibrations [5,26]. This early attempt hinted at the possibilities associated with tactile stimulation in terms of the role that they might play in enhancing the immersiveness of entertainment experiences. In addition to the *Earthquake* movie, Sensurround was also used in films such as *Rollercoaster* (1977), *Midway* (1976), *Battlestar Galactica* (1978), and *Mission Galactica: The Cylon Attack* (1979). In the latter cases, vibrations were used to stimulate physical experiences such as the vibration of rollercoaster rides, engine noise, explosions, and space battles through extended bass frequencies and specialized soundtracks. Ultimately, however, Sensurround was only ever associated with five films and failed to catch on commercially. The reason for this, such as high costs, will be discussed in more detail later (see also [5]).

2.1.2. Force Feedback

Non-wearable haptic interfaces such as the Phantom Omni allow the user to interact with virtual objects using a pen-like handheld device. While this device enables detailed tactile interactions, such as providing users with force feedback to simulate the texture or resistance of virtual objects, its ability to create a fully immersive virtual world has not yet been studied, that is, the interface is primarily effective for localized interactions but may not evoke the same level of multisensory immersion as more advanced or wearable haptic systems. The SPIDAR-H provides haptic sensations to both hands through strings attached to motors, adjusting the tension in order to generate the appropriate force feedback [11]. For instance, the *Touch and Explore* VR game developed by Kumar [49] uses a low-cost arm-based motion restriction device, rather than the Phantom Omni, thus allowing the player to interact with the virtual environment. While both provide force feedback, Kumar's device highlights the potential of low-cost alternatives to enhance haptic interaction in VR.

2.1.3. Ambient Tactile Cues (Wind, Heat, etc.)

In addition to vibrotactile stimulation and force feedback, ambient environmental, or contextual, tactile cues such as wind and heat can also be used to simulate real-world ambient environmental conditions. Morton Heilig's Sensorama simulator was one of the earliest explorations in this type of passive immersive multisensory virtual experience [50]. This device was designed to engage multiple senses, including sight, sound, smell, and touch—the latter through vibrations and wind (see Figure 1). Although the Sensorama simulator lacked interactive elements that are essential for a full VR experience, it nevertheless proved to be a pioneering multisensory experience that may well have inspired future researchers. As far as we have been able to ascertain, the Sensorama simulator did not allow users to control elements such as the speed of the motorbike, thus making this more of an individually experienced passive immersive multisensory experience augmented by olfactory and tactile stimulation (vibration and wind) rather than necessarily an interactive one (as such, it does not count as an example of haptic VR nor even of VR with tactile augmentation).

More recently, multisensory storytelling experiences such as *Season Traveller* demonstrate how wind, thermal, and olfactory stimuli can be integrated in order to heighten the user's sense of presence in a virtual environment [51]. The system combines thermal feedback through Peltier elements (positioned on the back of the user's neck) and wind simulation (directed towards the user's face via small fans mounted on a micro servo motor below the head-mounted display; see Figure 1). The multisensory version of the storytelling experience was found to significantly enhance the richness of the experience in a study with 20 participants. Specifically, the *Season Traveller* configuration (M = 0.69, SD = 0.28) showed a notable improvement as compared to standard audio–visual VR (M = 0.5, SD = 0.3; $p = 0.039$). Note, once again, how the tactile effects target only a small area of the body, such as bare skin sites (on the head), which one might imagine would limit the possibility of experiencing any kind of full-body immersion (though see Section 1.7). Given that *Season Traveller* did not include any kind of interactive feedback resulting from a user's movements, it is, once again, more akin to the passive multisensory storytelling associated with the Sensorama simulator than a genuine example of haptic VR.

Devices such as the sensory reality pods from Sensiks potentially further push the boundaries of multisensory storytelling by offering creators the possibility to stimulate environmental conditions such as vibration, wind, and thermal cues [52], thus demonstrating the potential for enhancing storytelling through multisensory stimulation. The empirical evidence that has been published to date suggests that even basic environmental feedback—such as wind or vibration—can significantly enhance the sense or immersion in VR. For example, adding wind (using eight large fans on the floor to create a more realistic environment) increased the sense of presence by 12.2% compared to merely visually rendering wind in Giraldo et al.'s [53] recent study, which involved active user interaction within the virtual urban space. (Similarly, Gallace and Spence [8] also anecdotally highlight the profound effect that the use of even a simple fan to simulate wind effects can have on realism and immersion in the VR experience in the context of multi-million-pound driving simulators.) Such findings help to demonstrate how multisensory wind stimulation, even though of a relatively low-tech form, can nevertheless still contribute to the more immersive and engaging experience of virtual environments. By stimulating the senses directly and without complex interpretation, such environmental cues help to blur the lines between virtual and physical spaces, thereby enhancing the overall VR experience.

Another recent example of multisensory VR experiences that included wind effects was provided by *TREE*, an experience designed to evoke empathy for the challenges of deforestation and climate change [54]. The idea behind the experience is that the user, through the VR visuals, perceives themselves as a Kapok tree from a first-person perspective, accompanied by haptic feedback on the back, wind, and scents (see Figure 1). While the pattern of vibrations is designed to contribute to the physical sensation of movement or impact, it is the combination of multiple sensory cues—vibration, visual effects, and distinct smells (earth, foliage, and smoke)—helps the user feel as though they are growing from a seed into a tall tree, eventually being cut down. Although no one not knows quite what is feels like to be a tree (if it feels anything at all!), the alignment of sensory and visual elements was said to create a coherent experience, allowing users to engage with the environment. The experience uses temporal, spatial, and semantic congruence to synchronize sensory elements, enhancing the immersive and emotional impact of the virtual environment [54]. While the experience aims to enhance immersion through synchronized sensory elements, there are currently no experimental data available to verify the effectiveness of these sensory interactions.

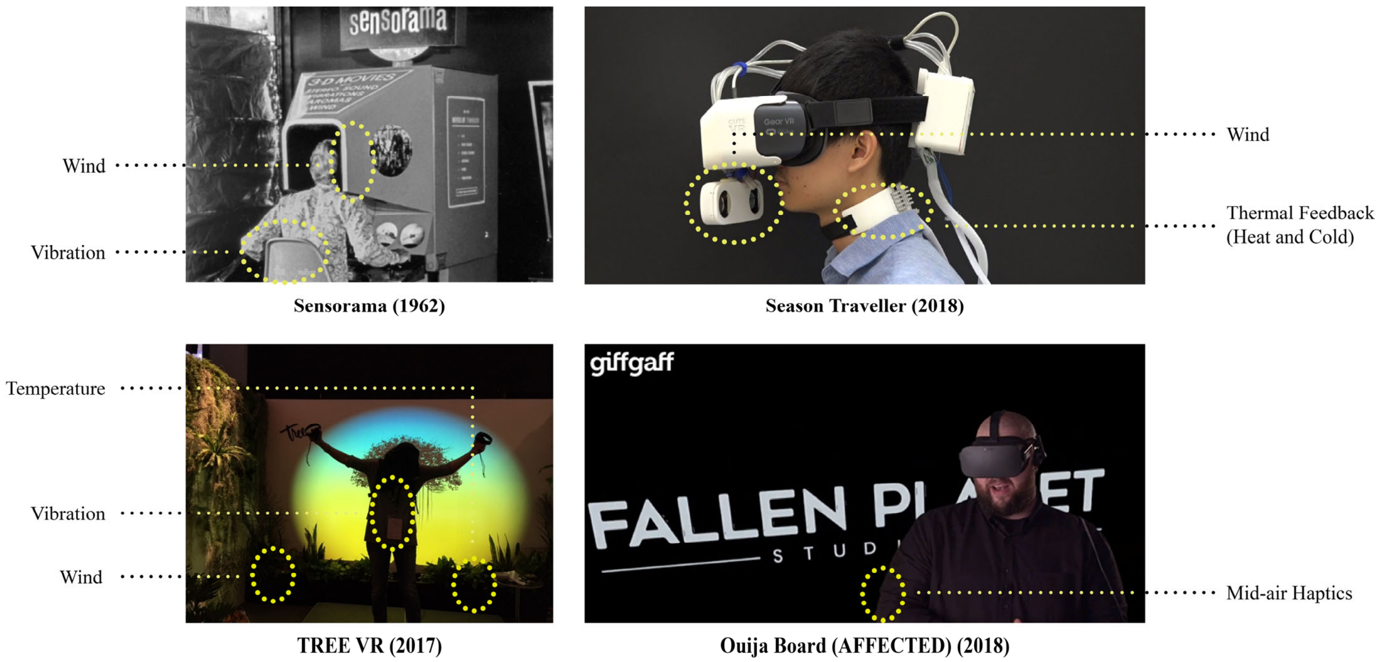

Figure 1. Multisensory VR experiences incorporating different kinds of haptic feedback (it should be noted that the placement of wind and temperature units in the TREE VR diagram is provided for illustrative purposes only, given that the exact locations of these elements within the installation are not specified in the source materials) [55–58].

2.1.4. Mid-Air Haptics

While tactile feedback can undoubtedly add a new dimension to immersive experiences, it is important to stress how very few of the devices that have been mentioned thus far in this review have made it out of the lab into a public entertainment setting. One notable exception is provided by Ultrahaptics, a mid-air haptic feedback technology that allows the user to feel tactile sensations in mid-air without any physical contact (see Figure 1). For instance, the use of mid-air haptics in the VR experience *AFFECTED: The Visit* by Fallen Planet showcased how haptic feedback can offer a uniquely engaging experience [59]. This experience, which involves the user interacting with a Ouija board, highlights the potential for haptics to provide experiences that simply cannot be conveyed naturally through the other sensory channels, i.e., the feel of spirits on the board has no auditory or visual equivalent [6].

Users' descriptions of mid-air tactile experiences highlight the diversity of sensations that such a non-contact technology can deliver to the hand. For example, at lower frequencies (16 Hz), sensations such as "puffs of air" or "tapping", reminiscent of weak air flow or light physical touches, are described. At higher frequencies (c. 250 Hz), sensations akin to a "breeze" or "flowing water" are described, offering a smoother, more continuous tactile experience (see [60]) (such an interpretation might presumably require some inferential work on the part of the user to interpret the stimulation, which could potentially reduce the likelihood of delivering immersive experiences by means of such technology). At the same time, however, the unnatural and/or unfamiliar nature of this form of tactile stimulation likely means that the user will have to infer what the stimulation is meant to stand for or relate to.

2.1.5. Electrotactile Feedback

Haptic devices capable of delivering force and strong vibrotactile feedback can sometimes be large and difficult to transport; a possible solution for this could be electrotactile feedback. This technique uses electrical currents applied via surface electrodes to directly activate nerve fibres in the skin, thus simulating tactile experiences [61–63]. Compared to other tactile devices, electrotactile displays are simpler to design, involve lower power consumption, are more portable, and cost less as the number of stimulators increases, compared to traditional mechanical vibration or force-feedback systems, which tend to require more complex and expensive hardware [63,64]. However, it may currently face issues related to its invasive nature, which can sometimes cause discomfort or even anxiety, as well as difficulties in integration into real-life applications ([64]; see Spence [65], on the use of electrotactile displays in the context of sensory substitution devices).

According to Kourtesis et al. [63], one early exploration involved the use of electrotactile feedback in a handheld device called the Palm Touch Panel [66]. This device, attached to a mobile device, used tactile cues to reduce users' reliance on visual information/attention by delivering sensations that corresponded to touch inputs on the screen. In an informal study with five participants, the feedback described the experience as "if they were touching their own palm". This device could potentially be used in more immersive environments, such as VR, to provide more realistic tactile feedback. However, addressing issues such as inadequate sensor sensitivity and user discomfort with the idea of electrotactile feedback will be challenging.

Another example of electrotactile feedback was a device called Tacttoo, developed by Withana et al. [67]. It is an extremely thin (less than 35 μm) interface that attaches to the user's skin and provides electrotactile stimulation. The researchers integrated Tacttoo with VR to aim for a more realistic user experience compared to traditional VR setups that rely solely on visual and auditory feedback. For example, when users touch a virtual tree, the system provides different real-time tactile feedback depending on the surface, potentially contributing to a more engaging experience. The Feel-Through Experiment with 10 participants showed that Tacttoo only decreased their tactile sensitivity slightly, and participants reported that it was so comfortable that at times they were unaware of its presence and could not feel it [67].

Electrotactile feedback, combined with VR, is designed to address the limitations of traditional rehabilitation systems by making the process more immersive and responsive. In Li et al.'s [64] rehabilitation platform, electrotactile feedback was used in VR to simulate grasp and release movements as they occur in real life. Electrical impulses were directed to the hand or arm, replicating the sensation of force that is experienced when grasping objects. In the VR environment, real-time visual feedback, such as hand deformation, is provided alongside electrotactile feedback, which offers haptic sensations. Compared to the no-haptic feedback condition, electrotactile feedback was found to increase the efficiency of rehabilitation and enhance the user experience by reducing the user's reliance on visual cues, thus potentially making the experience more immersive. While the feedback was effective, the system has only been tested on a small group of ten healthy participants and needs further evaluation on participants with limb injuries or amputations [68].

2.2. Passive Haptics in VR and Mixed Reality (MR)

Passive haptics refers to non-interactive tactile feedback that users experience without actively controlling or manipulating the virtual environment. One example comes from a study by Dinh et al. [69] that provided evidence via a large-scale study involving 322 participants. A significant increase in ratings of presence was documented with the addition of auditory and tactile cues. However, as both sensory elements were involved, it was not possible to determine which element was the key contributor to the increased sense of presence or whether, in fact, it was their combined influence that was doing the work.

In addition, passive haptic VR experiences such as *Season Traveller* and *Sensiks* also demonstrate the potential of ambient tactile cues such as wind and thermal feedback to enhance the immersiveness of an experience. Although these experiences primarily target specific areas of the body, they nevertheless showcase how passive environmental effects can contribute to a heightened sense of realism and engagement for those who find themselves in a given virtual environment. Similarly, tactile interaction systems, especially those designed to elicit human emotions, have been used to demonstrate how tactile feedback not only enhances the sense of presence but also conveys affective information, such as calming or exciting the user through the modulation of tactile sensations [70]. These systems raise the possibility of bridging the gap between passive touch and emotional tactile/haptic engagement, thus providing a more emotionally immersive experience.

3. Development of Haptics in Immersive Entertainment Experiences

> *"Going to the Feelies this evening, Henry?" enquired the Assistant Predestinator. "I hear the new one at the Alhambra is first-rate. There's a love scene on a bearskin rug; they say it's marvellous. Every hair of the bear reproduced. The most amazing tactual effects"*. [71]

This literary reference from Aldous Huxley's *Brave New World* [71] describes "the Feelies", a form of entertainment where every sensation, down to the tactile experience, is replicated. Huxley's literary vision stands as an early aspiration for what haptics in entertainment, including VR, could offer—by adding a sensory dimension to enhance the experience (it is interesting to consider whether Huxley's interest in touch-augmented cinema is related to the "syn-tattilismo" movement promoted by the Italian Futurists in their writings during the opening decades of the 20th Century (e.g., see [72])). It is interesting, in hindsight, to consider how Huxley's description leaves it entirely open as to whether this experience was passively presented, or actively explored, as perhaps suggested by the name "The Feelies".

3.1. From the 1950s to the Early 1990s: Foundation, Exploration, and Early Technologies

In the 1950s, Morton Heilig laid some of the groundwork for multisensory experiences, publishing an article on multisensory cinema in 1955 [73], followed by his famous 1962 patent describing the Sensorama simulator (see earlier discussion), a device designed to engage multiple senses. This early exploration of immersive multisensory entertainment provided an ideational landscape for Ivan Sutherland's 1965 theoretical concept of "the ultimate display", which he envisioned as a fully immersive virtual system engaging visual, auditory, and tactile sensations, where users could interact with the virtual environment as if it were real. It has been widely suggested that this concept helped to lay the foundations for modern VR [74]. Since then, visual and auditory technologies have helped to make VR experiences increasingly realistic, though, as has been mentioned already, the development of haptics has tended to lag some way behind [75].

In the context of VR experiences, auditory technologies help to deliver dynamic, spatial audio that continuously adapts to the user's movements and head position within the virtual environment, thereby responding in real time to create a heightened sense of presence and immersion [76,77]. It is worth highlighting how this differs fundamentally from traditional audio formats such as stereo recordings/reproduction, which provide a spatialized but fixed (i.e., non-interactive) sound experience.

In 1993, with the advancement of haptic rendering technologies, the Phantom was developed, providing a foundation for the incorporation of haptic technology in VR [78]. However, while it allowed for haptic interactions with virtual objects, its contribution to creating a fully immersive VR experience is limited, as it primarily focused on localized force feedback (i.e., typically applied to the thumb and index finger inserted in thimbles) rather than a more comprehensive multisensory experience. While Phantom-type devices have typically been developed for research and training purposes, they have rarely been used in an entertainment setting.

3.2. From the Late 1990s to After 2000: Advances in Haptic Technologies and Wearables

As haptic technologies advanced in the late 1990s and early 2000s, researchers such as Dinh et al. [69] and Hoffman et al. [33] started to explore how adding sensory inputs, such as tactile and auditory feedback, could be used to enhance the user's sense of presence in VR by providing immersive sensory experiences that complement, but are not limited to, visual feedback. These studies laid important groundwork for future research into multisensory VR systems. Nowadays, many VR experiences use wearable technologies such as haptic gloves and suits to deliver tactile stimuli [79]. For example, haptic gloves allow users to feel and manipulate virtual objects directly with their hands (e.g., [80,81]), while haptic suits and vests, such as the Teslasuit, provide physical feedback across multiple areas of the body surface using electrostimulation and vibration motors.

A study by Alma et al. [82] demonstrated that such haptic feedback can enhance entertainment experiences by increasing immersion and the plausibility of the experience. In their study, participants wearing a Teslasuit—a full-body haptic suit designed to simulate physical sensations through electrostimulation and vibrotactile feedback, while also incorporating motion capture and biometric data for enhanced human performance—watched a short film. The biometric data, such as related to heart rate and muscle tension, are tracked in real time and can be used to dynamically adjust the intensity of haptic feedback based on the user's physiological responses, thereby optimizing engagement and performance [82].

They reported greater plausibility in the experience, which likely contributed to a stronger sense of presence, as the more believable the virtual environment felt, the more immersed participants became. However, the electrostimulation used to simulate physical impacts was described as feeling somewhat unnatural. Indeed, it was sometimes misinterpreted as an electric shock rather than as the intended tactile sensation. Such results therefore suggest that while haptic feedback can significantly boost immersion, the accuracy of sensation matching remains a challenge for certain types of physical feedback.

In recent years, tangible interactive systems have been used to further explore how tactile feedback can be designed to communicate specific emotional states through morphing interfaces or temperature changes, indicating that tactile systems not only provide realistic sensory feedback but can also enrich emotional engagement through affective haptics [70]. While tangible interactive systems and tactile feedback technologies often complement pre-existing visual and auditory VR, they also play a crucial role in delivering tactile feedback that directly engages the user's sense of touch, functioning alongside other sensory inputs to enhance immersion. A selective overview of the different haptic VR technologies, the body sites that they stimulate, and the types of touch that they are capable of delivering is presented in Table 2. Figure 2 highlights the milestones in the development of haptic technology and its integration with VR, while Figure 3 provides a categorization of these key milestones.

Table 2. Overview of Haptic VR Technologies, Stimulated Body Sites, and Types of Touch.

VR Example	Haptic Device	Stimulated Body Sites	Types of Touch
Feelies [71]	Hypothetical multisensory system	Whole body	Tactile
Sensorama [50]	Sensorama simulator	Upper body	Vibration, wind
Ultimate Display [74]	Conceptual VR system		
Phantom Omni	Phantom Omni	Hand/fingers	Force feedback
Hoffman et al. [33]	VR setup with physical objects	Hand	Physical touch
Dinh et al. [69]	Passive haptic elements	Various body sites	Vibration
Palm Touch Panel [66]	Electrotactile panel	Palm	Electrotactile feedback
SPIDAR-H [11]	SPIDAR-H	Hands	Force feedback
Season Traveller [51,83]	Fans, Peltier elements for wind/thermal feedback	Head and specific skin sites	Wind, thermal
Tacttoo [67]	Tacttoo	Hand	Electrotactile feedback
Li et al. [68]	Electrotactile rehabilitation device	Hand, arm	Electrotactile feedback, force simulation
Teslasuit in film experiment [82]	Teslasuit	Upper body focus	Vibration
Ultrahaptics in *AFFECTED: The Visit* [59]	Ultrahaptics (mid-air haptics)	Hands	Mid-air tactile feedback
Sensiks [52]	Sensory reality pod	Whole body	Wind, thermal
TREE VR [54]	Vibration device for back, wind effects	Back, bodily wind stimulation	Vibration, wind
Touch and Explore VR [49]	Arm-based motion restriction device	Arm	Force feedback

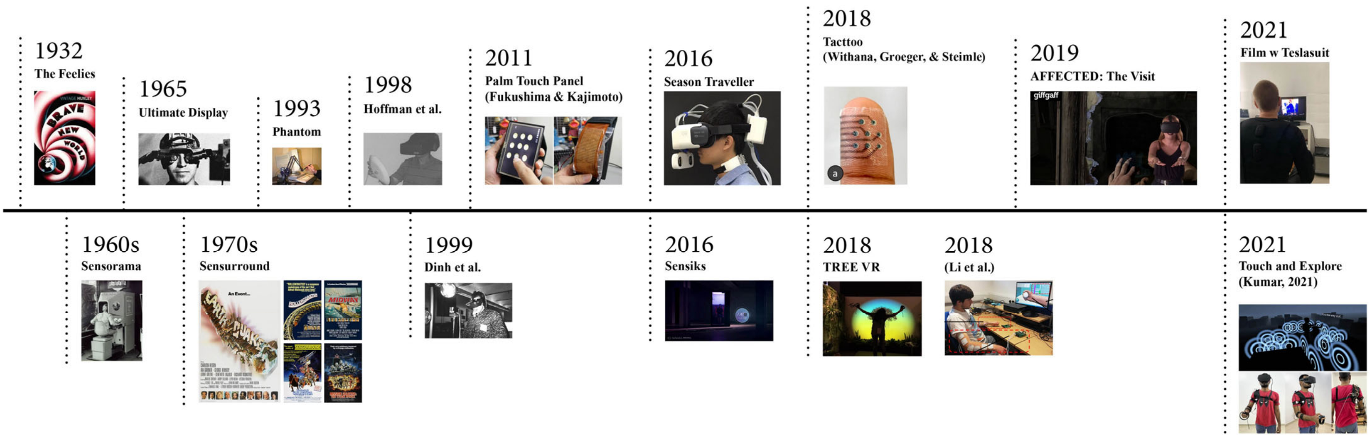

Figure 2. Timeline of key multisensory VR/experience developments, incorporating different kinds of haptic feedback [33,49,52,55–58,66–69,78,82,84–90].

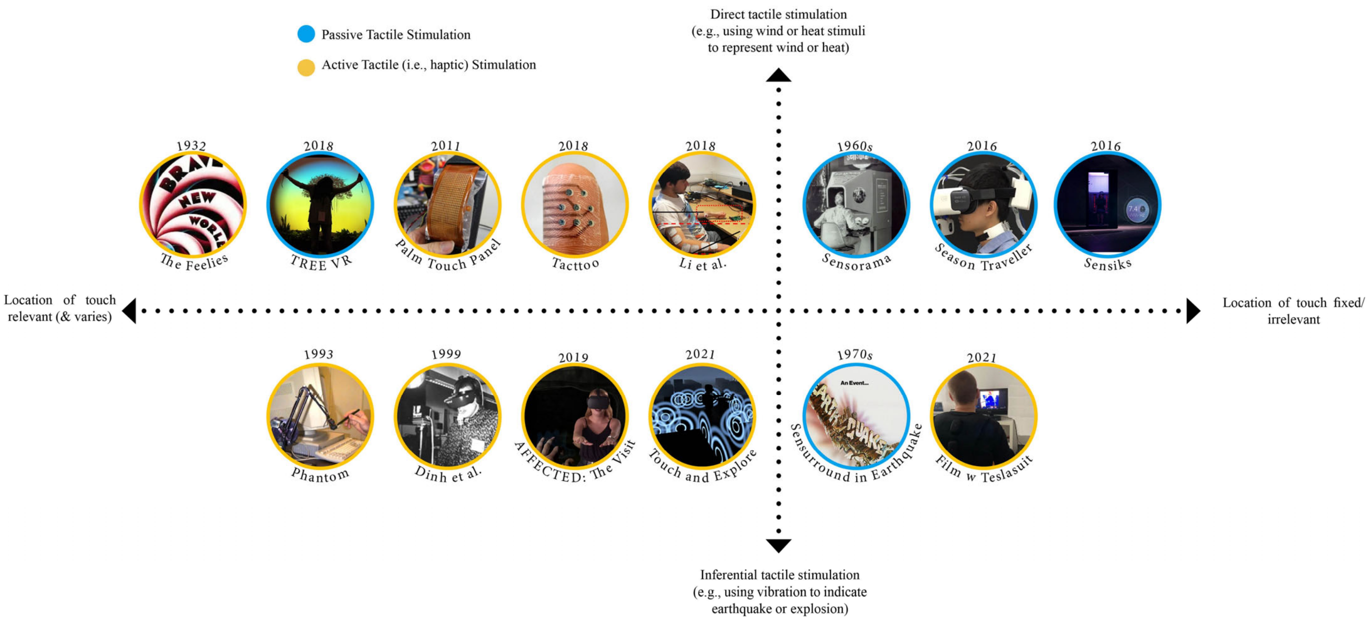

Figure 3. Categorization of haptic technologies related to immersive storytelling and VR [49,52,55–58,66–69,78,82,84,86].

3.3. Future Direction and Challenges

Despite the progress in haptic technologies, significant challenges remain. Tactile feedback in VR can be categorized into two dimensions. Similar to the case for scent (i.e., olfactory stimulation in VR; see [91]), the first dimension is based on user interaction: active manual feedback, such as from devices like Phantom Omni, allows users to directly manipulate virtual objects in order to generate, and thus experience, haptic responses. By contrast, passive ambient feedback, such as a wind effect, is typically delivered to the user without their necessarily having to take any action. The second dimension relates to the nature of interpretation: some feedback, like wind and thermal effects, deliver direct physical sensations that presumably do not need to be interpreted, whereas devices like Ultrahaptics or haptic backpacks tend to provide more abstract feedback that may require the user to mentally interpret the sensation, in terms of what the technology/stimulation is supposed to represent.

For instance, Clark [92] reviewed the warzone-themed multisensory experience *HERO*, where a VR headset (stimulating the visual and auditory senses) and a haptic backpack were used to transmit vibrations (the exact number of vibrations was not specified in the available sources) that were synchronized to the explosions that were presented in the simulation. However, while such solutions have been presented in public entertainment settings previously, haptic backpacks are not widely available amongst the gaming community; hence, such a solution is unlikely to have much of a role in the home entertainment market for the foreseeable future. As a result, more accessible forms of tactile feedback, such as vibrations in handheld player consoles, are often used in the context of home gaming (see Gao and Spence [4], for a review). However, it remains unclear whether the vibrating handheld devices that are commonly used can necessarily deliver anything like the same level of impact/effectiveness as the tactile sensation delivered by a haptic backpack, which, while still primarily relying on vibration, covers a larger area of the skin surface, potentially offering a more immersive physical experience (at least when trying to convey certain types of sensation).

Looking to the future, tactile feedback has the potential to enhance the realism of VR and mixed reality (MR) experiences, particularly as devices such as Apple's new Vision Pro currently lack this feature. The absence of tactile feedback in bare-hand interactions may affect both the accuracy and speed of user input and the overall user experience [93]. To address these challenges, some developers, including those in experimental settings on platforms like YouTube [94], are working to develop wearable devices like haptic gloves that are capable of simulating a range of tactile sensations when interacting with virtual objects. These gloves are designed to complement the highly realistic virtual environment. However, practical issues, such as varying hand sizes, present practical challenges in designing solutions that would work for everyone (i.e., no matter what their hand size).

While there is no definitive evidence that the absence of tactile feedback in systems such as Apple's Vision Pro necessarily reduces the user's sense of immersion, it is worth considering how the lack of haptic interaction might affect the overall immersive quality for certain users. Active tactile feedback in VR is designed to offer users immediate confirmation of their actions, such as feeling the texture of a virtual object or the force of impact during an interaction. Without tactile feedback, users do not receive immediate and clear confirmation of their actions, which can lead to accidental inputs or unintended interactions due to the lack of physical sensation, increasing the likelihood of user error.

4. Challenges and Limitations of Haptic Innovations in VR

4.1. Core Challenges and Limitations in Haptic VR Innovations

4.1.1. Technological, Financial, and Information Processing Challenges

The current high cost and limited accessibility of digital systems that are capable of delivering complex haptic VR currently limit their widespread availability in the marketplace [95]. Furthermore, it remains to be seen how much consumers would be willing to pay for such putatively enhanced multisensory experiences that engage/stimulate their body directly. Consider here only how the Sensiks sensory reality pod provides a multisensory platform that can be used to enhance passive multisensory experiences by providing environmental cues such as wind, heat, and sound, though its role as a VR enhancement depends on how it is used and what users perceive or believe about the experience. The cost of this stimulation device currently starts at somewhere around GBP 20,000 (approximately USD 25,000). This is obviously a big investment to acquire such an advanced multisensory stimulation system. Moreover, there are undoubtedly significant time, cost, effort, and expertise requirements associated with programming the necessary scenarios, stories, and games to fully enjoy the benefits of these systems [96].

In addition to financial challenges (which might be expected to become less prohibitive as a given technology becomes more widely available, due to the ensuing economies of scale), multisensory and haptic systems face several other challenges including technical issues, such as delays in the response to user inputs and actions, the quality of user experience, and device complexity. Difficulty in using these devices can negatively impact the immersiveness of the experience and the overall realism of the virtual environment. Haptic gloves, despite their use in experimental laboratory settings, can face standardization challenges due to varying hand sizes [97]; this also applies to other wearables. User comfort is another issue, as wires and electronic devices can restrict natural movement and thus diminish the user experience [98]. It should also be noted that, unlike vision, touch-based VR experiences are influenced not only by digital tactile stimulation but also by real-world physical tactile sensations from other parts of the user's skin, such as contact with air or clothing, and ambient environmental conditions like temperature, humidity, or wind, making fully immersive tactile experiences that much more challenging to achieve.

As has been mentioned already, one of the significant challenges with implementing tactile feedback in VR systems is the limited bandwidth of information processing through the skin surface, which affects how much information can be conveyed through the skin [8]. Unlike vision, which has a high processing capacity, the skin is not as well suited for delivering large amounts of detailed sensory data [11]. It is precisely such challenges that have doomed the effective development of tactile–visual sensory substitution systems (TVSSs), where touch is used to convey visual information, but the low bandwidth of the skin limits the detail that can be transmitted (see Spence [65], for a review).

4.1.2. Consumer and Developer Challenges

The lack of industry standardization (i.e., across platforms) poses a significant challenge, as different tactile systems may require different hardware components, such as haptic gloves, suits, or controllers, thus making it challenging for consumers to find sufficient value to warrant the purchase of such specialized equipment to stimulate their sense of touch. Furthermore, the fact that multiple devices are available across various systems likely further deters consumers from purchasing such devices in the first place (i.e., there is no standardization in the marketplace).

Looking to the future, designers need to engage with haptic technology in a meaningful way, rather than merely viewing it as a gimmick, in order to fully leverage its potential and thus enhance the overall multisensory entertainment experience. In relation specifically to the incorporation of touch in gaming applications, Birnbaum [99] notes that "in this set up, games will not know the number of peripherals available to them nor their haptic capabilities. Therefore, there is a need for layers of technology to transcode (convert the haptic signals generated in the game into real haptic feedback that can be executed by the various devices that the player is interacting with) and orchestrate haptic signals for each endpoint to convey the game designer's intent for the meaning of the haptics in the game. Although this vision is technically feasible today, it is hindered by a classic chicken-or-egg problem: Without the widespread availability and mainstream adoption of multi-channel haptic peripherals, content creators have little incentive to create these types of haptic experiences; and without content that can take advantage of multi-channel haptics, consumers have little reason to invest in these devices".

In contrast to the lack of standardization in VR haptic devices currently, it is worth considering how the gaming industry has long benefitted from standardized widely used controllers, such as Sony's DualShock or Microsoft's Xbox controllers, which provide game designers with a clear understanding of the available haptic capabilities, making it easier to design games that incorporate vibration feedback. Presumably, the manufacturers of both the technology and the games work within the same organization or have close connections, allowing for seamless integration. As a result, third-party developers do not need to develop haptics separately or after the game is completed—they can simply target the standardized controllers from the start. However, when it comes to haptics involving wearables, the same challenges seen in VR, such as a lack of standardization and interoperability, also arise.

Haptic VR may also encounter certain psychophysiological challenges. Prolonged exposure to haptic stimulation can lead to sensory overload or fatigue, which diminishes the immersive experience. In intense game scenarios or frightening narrative contexts, enhanced haptic feedback may further increase user nervousness, anxiety, and emotional responses [100]. To address these issues, designers should consider balancing the duration and intensity of haptic feedback, potentially incorporating cues for users to take breaks. This approach can help ensure a more comfortable experience while mitigating the psychophysiological strain on users.

4.2. Evaluations and Future Directions for Haptic VR

4.2.1. Creative Considerations

Forms of ambient tactile stimulation such as wind and heat are often passively and automatically perceived by users, which may explain why they are more effective in enhancing immersion [83]. These kinds of tactile feedback do not require additional interpretation, that is, they do not require the participant to do additional thinking and hence are unlikely to cause confusion [101]—wind is just wind and is experienced directly as such. However, if a Peltier heating/cooling element were to be used metaphorically, such as to convey a cold feeling in one's heart, it would align with research suggesting that temperature changes can evoke emotional responses [102]. However, it would presumably require some degree of interpretation, and it is unclear how challenging this would be for participants and how it might affect the flow of the experience. This contrasts with the vibration of a gaming console, which a user typically needs to interpret as referring to a specific event, such as being hit, changes in energy levels, time's up, etc. (see [4]).

As haptic feedback technologies become advanced, leading to increased immersion and further blurring the boundaries between virtual and physical experiences, it is possible that ethical concerns regarding user consent and potential psychological effects could emerge, especially as reports of verbal and physical harassment or unwanted interactions in virtual environments, such as the metaverse, have started to appear [103]. While there is limited direct evidence of widespread concern at present, designers and researchers should nevertheless remain vigilant and ensure that users are fully informed of the potential emotional, psychological, and physical effects of haptic interactions. Slater et al. [104] further highlight that as realism in VR increases, issues such as privacy, data security, and emotional impact may also intensify. Offering clear options for participation in these experiences and establishing safety protocols in virtual spaces can help mitigate any future ethical issues [105].

Furthermore, even if cost were not a factor, it remains unclear whether haptic technology consistently enhances immersion and the overall user experience or under what conditions it does so (cf. [106,107]). This uncertainty is partly due to the limitations of previous research, such as small sample sizes, which limit the possibility of drawing definitive conclusions.

4.2.2. Future Considerations

The current costs of dedicated hardware and programming and the lack of standardization across the industry represent temporary limitations to the broader adoption of haptic-enabled VR systems. While haptic-enabled VR systems offer the potential to deliver a wider range of tactile experiences, their current use is largely confined to specialized settings such as research labs, theme parks, and experimental storytelling environments, many of which are still in the experimental or prototype phase (e.g., *Season Traveller*; [100]).

Over recent decades, vibrating devices—such as those in game controllers and mobile phones—have seen a remarkable rise in popularity. These devices provide basic tactile feedback but are clearly very limited in terms of the range of kinds of tactile sensations required for immersive haptic VR. However, there are emerging innovations in haptic technology such as systems that can simulate wetness, temperature changes, and other complex sensations.

While increasing accessibility to mainstream consumers could undoubtedly unlock some new possibilities in terms of entertainment and learning, further research is needed to clearly demonstrate the benefits of haptic systems before encouraging widespread adoption. To fully realize the potential of haptics, the entertainment industry will need to address cost, standardization, and usability issues and, by so doing, hopefully ensure that haptic systems become more accessible to mainstream consumers [108]. Potentially relevant here, recent advances in soft and stretchable haptic actuators have started to attract attention, as researchers aim to enhance both the wearability and comfort of haptic devices (see [14], for a recent review). Recent research has also focused on electrohydraulic systems and soft actuated interfaces in order to try and make haptic VR experiences somewhat more comfortable for the user. Soft interfaces potentially offer more vivid tactile feedback while at the same time reducing the weight of the device, thus making them more suitable for immersive VR applications [14].

Finally, over and above any technical considerations, it is important not to forget the profound and fundamental limitations in human tactile attention and information processing abilities for stimuli that are presented to the skin surface, especially when the visual and/or auditory modalities also happen to be stimulated independently [8,65].

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