Using the Visual Language of Comics to Alter Sensations in Augmented Reality

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Figure 1: We use visual elements from comics to augment objects and activities. Shown here—for illustrative purposes—are 3rd person renderings of these elements. Based on a design space we derive from the literature on comics, we build eight augmented reality demos where participants see these effects in 1st person, and then evaluate the effects through a qualitative study.

ABSTRACT

Augmented Reality (AR) excels at altering what we see but non-visual sensations are difficult to augment. To augment non-visual sensations in AR, we draw on the visual language of comic books. Synthesizing comic studies, we create a design space describing how to use comic elements (e.g., onomatopoeia) to depict non-visual sensations (e.g., hearing). To demonstrate this design space, we built eight demos, such as speed lines to make a user think they are faster and smell lines to make a scent seem stronger. We evaluate these elements in a qualitative user study (N=20) where participants performed everyday tasks with comic elements added as augmentations. All participants stated feeling a change in perception for at least one sensation, with perceived changes detected by between four participants (touch) and 15 participants (hearing). The elements also had positive effects on emotion and user experience, even when participants did not feel changes in perception.

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality**; *Visualization.*

KEYWORDS

augmented reality, comics, sensory augmentation

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1 INTRODUCTION

Augmented reality (AR) excels at changing how we see the world, such as by adding things to the environment that do not exist [9], changing the appearance of things that do [34], hiding parts of the environment from our view [16], and even making hidden things visible [50]. However, seeing is not the only way we perceive our surroundings, we also hear, smell, and feel the world around us. Most current AR systems consist of headsets focused primarily on our sight, neglecting the other senses we perceive our environment with. This narrow focus is because altering non-visual aspects of reality is a challenge due to tangible interactions with the real world. We cannot perceive all physical properties of virtual objects, nor can we easily change the physical properties of the actual environment. This extends to our actions and activities, where AR can provide additional information related to them but lacks an established way to augment them directly. For example, it is unclear how AR could possibly make us feel stronger when lifting weights or perceive a phone's vibration more intensely.

A potential approach for communicating non-visual sensations can be found in comic books, a medium that has successfully bridged this gap between visual form and non-visual sensations. Comic artists have developed a rich visual language with a large vocabulary of symbols corresponding to specific meanings [99], such as onomatopoeia (words that phonetically describe sounds) and emanata (symbols near a character's head that convey emotions). These elements have also been used in movies (such as Scott Pilgrim[1]), video games (such as NFS Unbound[2]), and music videos (such as Without Me by Eminem [3]) to create unique visual effects, improve user experience, and increase motivation [36]. Whether these elements still achieve similar effects when embedded into the real world through AR is an open question as interactions with the real world do not involve the level of suspension of disbelief that media consumption through a screen does.

Our work uses elements from comic books in AR environments to represent and enhance non-visual sensations through visual augmentations. We add comic elements to annotate objects and activities, using AR to enhance how users feel, move, hear, or smell. Inspired by previous works on adding annotations to change the perception of user actions [35, 87, 91], we explore whether comic book elements can achieve similar effects. While comic-inspired annotations to convey information (such as interactivity or state) about objects or actions can be found in existing AR and Virtual Reality (VR) applications, we use comic elements to convey effects that cannot be rendered in AR/VR directly (such as stinkiness or the feeling of being stronger). Altering the objects themselves or their appearance would require additional hardware or advanced display technologies that may be impractical. Hence, our work indirectly adds sensory information onto the real world and studies the effects this has on users. Comics are an art form known to evoke not just a sensory but also an emotional response [55]. Therefore, we investigate how comic elements affect the user experience of performing everyday tasks.

[1]https://www.imdb.com/title/tt0446029/
[2]https://www.ea.com/en-gb/games/need-for-speed/need-for-speed-unbound
[3]https://www.youtube.com/watch?v=YVkUvmDQ3HY

Through an analysis of the comic studies literature, we created a design space that organizes comic book elements into four categories based on the sense they aim to represent and three categories of visual representation (i.e., text, lines, and symbols). We then built a set of eight demos to illustrate how to use visual elements to create non-visual sensations by realizing examples of each category of our design space. Through a qualitative user study (N=20), we evaluated what users feel about the non-visual properties we aim to convey and what other effects these annotations have, such as increasing motivation or enhancing user experience. Our results show that the comic elements were fully understood by at least 75% participants for all but one of the elements. Participants stated that the sensations felt enhanced or different compared to the real world in about half of the total trials (N=78/160) of our study. The elements made the interactions playful, enticing, curious, boosted the participants' emotions, and impacted their self-perception and motivation. These effects were mediated by the appearance of the comic elements, their movement, and timing.

With this work, we make the following contributions:

- A design space of comic book elements that convey non-visual sensations along sensory and visual dimensions.
- Eight demos that instantiate different kinds of non-visual sensations for concrete everyday activities.
- Findings from a qualitative evaluation (N=20) of people's experiences and perceptions when comic elements are added to objects and their actions in the real world.

2 RELATED WORK

Our work adds visual elements from comic books to actions and objects to enhance non-visual sensations and the experience of interacting with the environment. Thus, our work is related to (1) research on embellishments (elements that add detail) and the effects they can produce and (2) vision and body-altering perceptual manipulations in XR. Lastly, we discuss (3) how previous HCI research has leveraged visuals from comic books.

2.1 Embellishments for Actions and Objects

In gamification, the concept of juiciness refers to "design elements that support information already conveyed by other means" [35], for example, a particle explosion on collecting a coin. Hicks et al. [35] studied the use of visual embellishment on players' actions and found that they contribute to player experience and may also contribute to perceived competence. Similarly, Singhal and Schneider [87] explored the use of haptic embellishments by modifying the haptic signals to support visual juicy elements and found a positive effect on enjoyability along with player and haptic experience.

Another related concept from games is Visual Delegates [57, 59, 60]—visual elements added to games to convey non-visual sensations felt by a character by, for example, colored screen edges to depict pain. Beyond screen-based games, these elements have also been applied to virtual reality games [58, 60]. These elements are very similar to our comic elements but use a different set of symbols that are rooted in games and can also apply transformations to the entire view of the player, which may be inappropriate for AR as it breaks the effect of looking at the real world.

Adding visual cues to a VR scene can influence user behavior and experience. Blaga et al. [10] added visual cues to represent the temperature of the liquid inside a virtual cup coffee mug and found that the cues influenced grasp locations despite the mug not being real. Moullec et al. [61] used multi-sensory cues to convey a user's cardiac and respiratory activity in a VR walking scenario, such as visible breathing in front of an avatar's face. This led to an increased sensation of effort and the user's actual breath synchronizing with the virtual breath. Langbehn et al. [49] studied the effect of adding motion blur to movement in a VR scene but did not find any effect on distance or speed estimation. These works focus on VR and on quantitative evaluation, and they did not study the user experience of the feedback. Exploring effects very similar to comic books, Eckhoff et al. [23] found that the pain threshold could be modulated by adding a 3D flame effect or blue fluid covering participants' hands when they touched a hot or cold object. These examples show that even if users know a visual annotation is not real, these annotations can still cause changes in action perception. For our study, we extend these works to a specific class of annotations inspired by comic books and evaluate if they work in the real world.

Audio embellishments have also been shown to affect the experience and perception of everyday activities. Tajadura-Jiménez et al. [91] changed the sound produced by a user when they walked to sounds they would produce if they had a thinner or heavier body. They found that high-frequency sounds cause users to perceive themselves as thinner than they are and increase motivation for physical activity. Gustosonic experiences are an area of research within Human-Food Interaction (HFI) which adds sound effects to eating. These effects have been studied in the context of eating ice cream [100, 101], eating potato chips [46], and drinking beverages through straws [102]. The effects of these sounds on eating include changes in consumption speed, appetite, and motivation.

2.2 Perception Manipulations in XR

VR provides complete control over what the user sees, which allows leveraging the property of visual dominance [72, 97] to produce a variety of illusions. One example of this is visual redirection, where a user's visual perception is slightly shifted to redirect their actions in the real world. For example, in redirected walking [76] slight rotations of the environment cause the user to believe that they are walking in a straight line even though their path in the real world is curved. Visual redirection has also been applied to hands to produce multiple haptic sensations through a single prop [5] and pseudohaptics [96]. Pseudohaptics has been used in VR to change an object's weight [83, 90, 105] along with other kinds of kinesthetic feedback [79, 80] or stiffness/softness [41] by adjusting the control display ratio. Visually representing haptic feedback has also been explored for robot-assisted surgery [30, 78]. In contrast to these pseudohaptics papers, which used psychophysics studies, we conducted an exploratory qualitative study. This allows us to better understand what potential effects our annotations could have rather than focusing the study on any one specific effect.

Visual properties of objects and humans (e.g., color or size) can also be manipulated. Based on the color-in-context theory Rixen et al. [81] investigated the modification of colors of an environment for subconscious benefits, for example, seeing an opponent wearing a red rather than a blue shirt in a competitive situation might change how dominant we perceive the person, which influences performance negatively. Visual manipulations have also been applied to users' avatars. Piryankova et al. [68] showed that embodying a body that is visually considerably smaller or larger than their physical body influenced participants' perception of ownership, agency, and self-localization. Besides body size, researchers have investigated visual changes of one's virtual hand [38, 85, 86] or body weight [47, 63]. In haptics for AR, examples of visual manipulation include altering object softness by projecting visually on the surface of an existing object [37, 73], changing weight by visually extending or reducing the length of a rod in a user's hand [31], and changing the perceived size of an object held in a user's hand by deforming the image of the hand [6]. While these works typically change an existing property of a virtual object or body, such as color, size, or weight, our work *adds* visual elements to objects or humans.

Virtual Performance Augmentation (VPA) is a term coined by Ioannou et al. [39] that refers to giving VR users the illusion of enhanced capabilities by exaggerating their actions in a virtual world. They used this idea by applying gain factors to a user's jump height and running speed in a VR exergame and found that this led to an increase in intrinsic motivation, perceived competence, and flow. Similarly, Wolf et al. [104] explored the use of augmented jumps as a locomotion technique for VR worlds and also found a positive effect on motivation, immersion, and presence. VPA has been studied in the context of biking in VR [51, 94] to explore the influence of different visual and haptic cues on a user's speed perception. Beyond manipulating physical parameters in the virtual world, Granqvist et al. [29] exaggerated the flexibility of a user's avatar in a VR kicking game that led to a higher kick height and increased perceived competence. Born et al. [12] explored VPA by manipulating the force exerted by a user when they punch enemies in a game by causing them to be thrown off to exaggerated distances. They found that this kind of VPA motivates players to perform strenuous activities but has no effect on the perceived competence or enjoyment that other works achieve. While suitable for VR, VPA is not applicable in AR since gain factors cannot be applied to actual speed or strength. Instead, our work explores whether visual annotations in AR can achieve similar effects to those in VPA. Comic books, which often feature individuals with enhanced capabilities, are a natural inspiration to achieve this effect.

2.3 Comic Symbols and HCI

Comics have been a focus of a variety of research in computer science [4], including comic content analysis [3, 17], comic content generation [13, 74], and user interaction with comics [1, 53]. In HCI, researchers have drawn inspiration from the visual language of comics to create new user interfaces and interaction techniques. EmoBalloon [2] is a chat application that generates appropriately shaped speech bubbles corresponding to the emotionality of the text message. Its evaluation revealed that differently shaped speech bubbles were more effective at conveying emotions than emoticons. Itou et al. [40] created another chat system inspired by manga where users communicate by adding comic frames instead of only text and found it to be more effective and expressive for conveying emotions than a regular text-based chat app. Comics have also

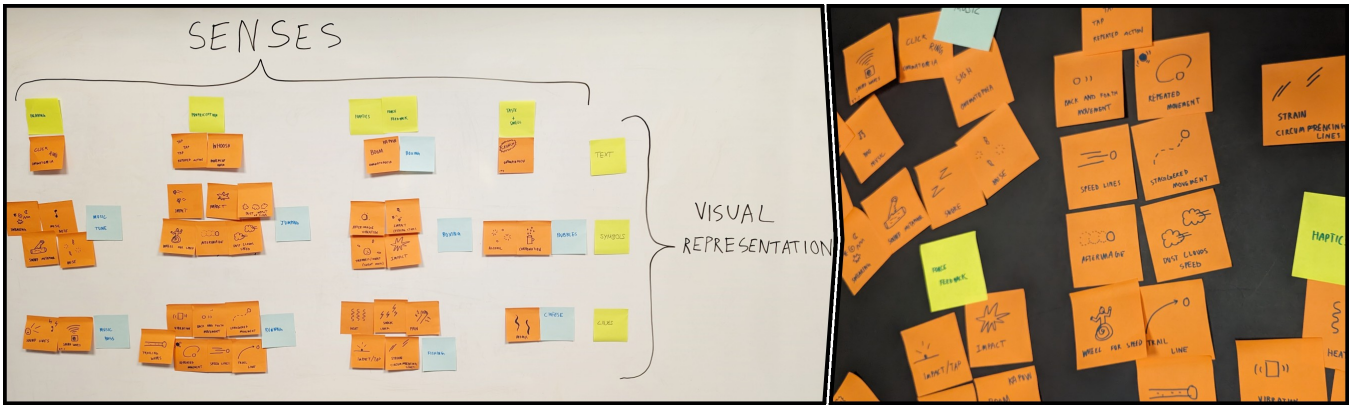

Figure 2: We used affinity diagramming to develop a design space for comic elements related to sensations. Showing here are the affinity diagramming in progress and examples of the post-it notes created for it.

inspired fabrication researchers, with Kazi et al. [44] presenting a tool to create sculptures from 3D animated models that visualize their motion in a static artifact. A common comic subject, superheroes, have inspired visualization [103] and VR researchers [82] to generate new techniques that grant enhanced capabilities to people.

Adding comic symbols to actions has been previously explored in the context of VR. Researchers have added onomatopoeia to sounds and studied its effect on user experience and perception. Fabre et al. [27] found that textual sound effects can lead to faster object characterization, change the perception of an object's properties (such as material), and influence volume perception. Oh and Kim [67] reported that such onomatopoeia can be used to guide user attention, convey object affordances, and enhance user experience overall. In Kapow! [14], Cauquis et al. explored the use of comic-inspired annotation to convey contact with virtual objects in the absence of any actual haptic feedback. They evaluated how six different feedback techniques influence user experience in terms of attractiveness, hedonic quality, and pragmatic quality but did not explore the effects on perception or user behavior.

These works demonstrate that comic book effects work in VR, albeit all of them are tested in environments with graphics that are animation-like rather than photorealistic. Whether these effects translate to the real world, despite the symbols still being in comic style or cartoonish, is a question we investigate through our work.

3 A DESIGN SPACE OF COMIC ELEMENTS FOR ALTERING NON-VISUAL SENSATIONS

We built a design space of visual comic elements and their represented non-visual sensations. Our design space exclusively includes visual representations based on comic elements (i.e., text, symbols, and lines), and thus is a subset of a larger design space of all visual representations. We chose comics as they are often focused on representing enhanced sensations like we aim to do and we wish to only annotate the world rather than changing it completely. We also considered cartoons and anime elements for inclusion in the design space. However, a common way for how they convey sensations is to leverage their non-static nature to exaggerate or morph bodies and objects when they are interacted with or moved [93], which requires further developments in AR inpainting technologies and is not in the scope of this work. Since cartoons or anime may also use visual effects in largely static scenes to convey sensation (such as dust clouds on a character falling), they share the symbols used by comics. Hence, our design space can be considered a subset of the cartoon-inspired design space.

The aim of this design space is to act as a quick reference for AR designers and developers to choose an appropriate comic element to convey or enhance the non-visual sensation they require for their application. The visual representation helps designers choose elements that suit a specific context (for example, using lines instead of symbols or words to avoid culture-specific associations) and provides structure to the space by grouping similar elements. Below, we describe the choice of the senses to be included in the design space and how we systematically collected and categorized the elements by going through the literature on comic studies.

3.1 Senses

The five-sense model is the most widely known model of the number of senses humans have and is usually credited to Aristotle, who mentioned it in his book "De Anima" [88]. However, many additional senses have been proposed [22, 45], and currently there is no established taxonomy of distinct senses [52]. With no widely accepted list of senses to draw upon, we decided to focus on what senses are relevant to AR. The senses we include in our design space are based on Speicher et al. [89], which identify five aspects of reality from past literature on mixed reality: audio, motion, haptics, taste, and smell. From this list, we take the corresponding sense to construct our design space.

3.2 Comic Book Elements

Background. To create a comprehensive list of elements used in comic books, we refer to comics studies, an interdisciplinary field combining concepts from semiotics, communication theory, rhetorical theory, media studies, and more. We refer to the following books and research articles for synthesizing a list of elements: (1) The Lexicon of Comicana [99] by cartoonist Mort Walker, (2) Comics and Sequential Art [25] by cartoonist Will Eisner, (3) The Visual

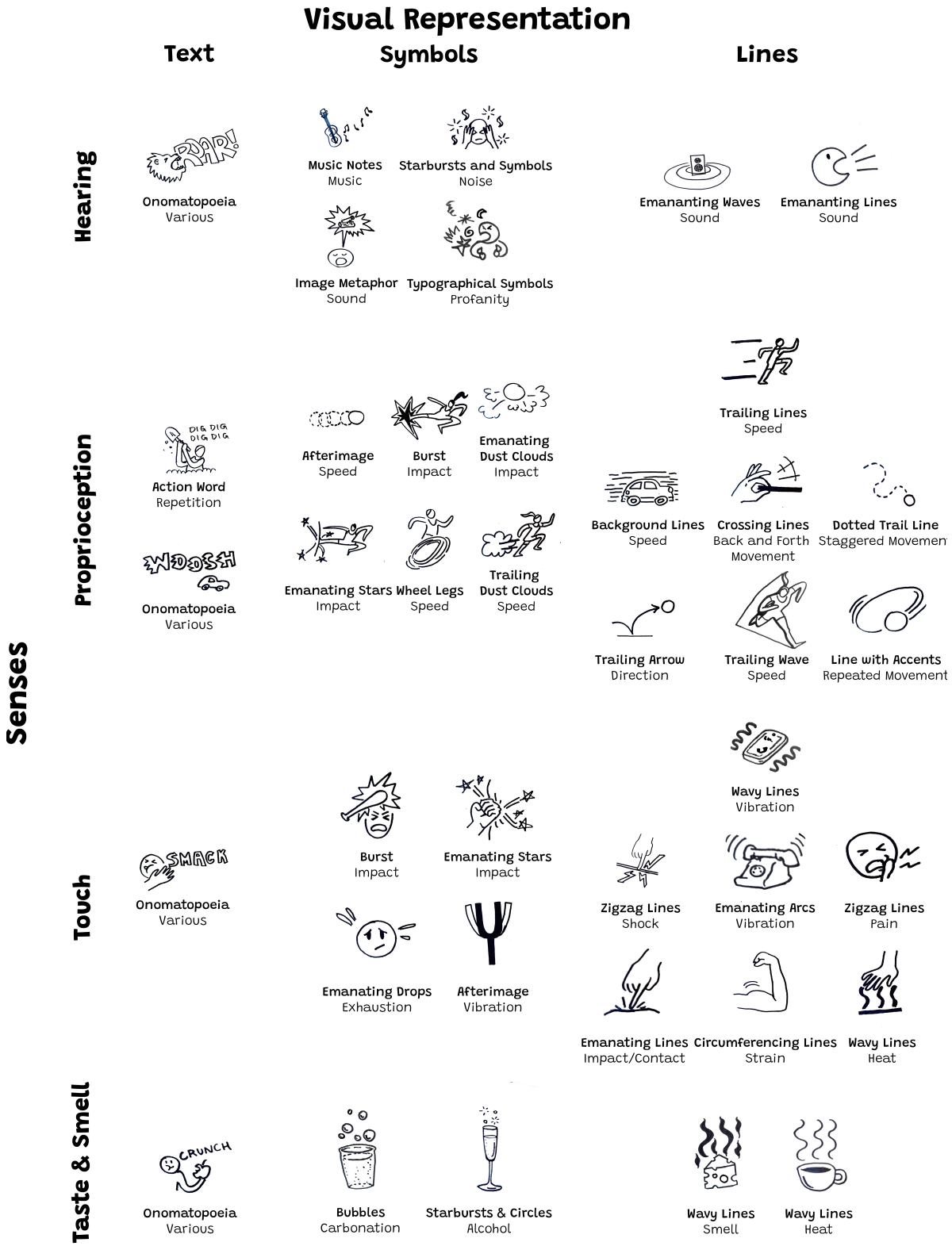

Figure 3: Design space of comic elements that convey non-visual sensations. We structure the design space by the four senses that are represented as well as the visual representation used to illustrate them.

Language of Comics: Introduction to the Structure and Cognition of Sequential Images [18] by cognitive scientist and comics theorist Niel Cohn, (4) The Vocabulary of Manga: Visual Morphology in Dialects of Japanese Visual Language [19] by cognitive scientist and comics theorist Neil Cohn and Sean Ehly, and (5) Understanding Comics, Reinventing Comics, and Making Comics [54–56] by cartoonist and comics theorist Scott McCloud.

Process. One author first went through the above list of sources and drew each element mentioned or used in it on a post-it note. We only focused on elements that convey sensory information and hence exclude elements that convey emotions (e.g., rain clouds over the head for sadness) and those limited to a very specific kind of object (for example, adding rounded corners to convey that a rectangle is a pillow). Elements that convey visual properties (e.g., shiny surfaces) were also excluded as vision augmentation is already possible in AR and not a focus of this work. We decided that the same kind of element corresponding to a different direction or magnitude would be considered the same (e.g., parallel vs. converging speed lines). This process led to a list of 39 elements.

Next, in a session with another author, each post-it was discussed and then placed in the appropriate sense category. Following the categorization into senses, we did another round of affinity diagramming to find other patterns in the effects, leading to categorizing elements by visual representation into either text-based, symbolic, or line-based elements. Text-based elements primarily included one or more words, while symbolic elements were more complex patterns with shapes or icons such as stars, and line-based elements were entirely composed of straight or wavy lines. We grouped elements with both lines and symbolic elements under symbols. With taste and smell being strongly intertwined and only one representation of smell being found in the literature, we combined them and thus ultimately focused on four senses: hearing, proprioception, touch, and taste/smell. Figure 2 shows the affinity diagramming in progress and examples of the post-it notes used.

Design Space. The final design space (Figure 3) consists of four senses (proprioception, hearing, touch, and taste/smell) and three types of visual representations (text, lines, and symbols). We name elements in our design space based on how they are drawn and mention what they convey. This is because our sources use different terms for the same elements and these terms are also often not self-explanatory (such as "hites" and speed lines for trailing lines). Some elements appear twice in our design space as they can represent both touch and movement depending on how they are used. This is because different works refer to kinesthesia as a part of touch or proprioception [22, 77].

4 USING COMIC ANNOTATIONS IN AR

We present eight AR demos (Figure 4) that illustrate the feasibility and functionality of the concept but also allow us to subsequently evaluate the experiences enabled through them. The demos were chosen to encompass every sense from our design space. Comic artists often combine various elements for larger effect [99] and our demos include such examples as well.

4.1 Apparatus

The demos were implemented using the Unity game engine. The demos used a mix of custom particle systems and some modified assets from the Unity Asset Store[4]. For all demos, except those of proprioception, we use the Varjo XR-3 as the AR headset to display our annotations. Our choice is based on the quality of its video pass-through, which has lower distortion compared to other available XR headsets, and its better development support as it does not impose limitations in accessing the passthrough feed. Since the Varjo needs to be tethered to a PC to work, we used a Meta Quest Pro, which works as a standalone headset, for the demos of proprioception to allow unrestricted movement for the user.

For tracking, we use an Optitrack setup consisting of 18 PrimeX 13W cameras (1.3 MP, 240 FPS). Along with the augmented objects, we also track the Varjo XR-3 using Optitrack markers instead of using its built-in tracking. This allows us to have a single coordinate system (the Optitrack's) to align virtual objects with the real world. The motion demo required no additional objects and thus only used data from the sensors on the Quest Pro to track the user's movements and the floor position. No controllers or hand tracking were used for any of the demos. Next, we describe each application and the targeted non-visual sensation.

4.2 Augmenting Proprioception

Background. Our proprioception demo seeks to convey enhanced speed and jumping capabilities. The most common representation of speed and motion in comics is through lines trailing an object or covering the whole background around it. The idea behind these lines representing motion is based on how fast-moving objects seem to leave streaks behind them [28]. Why these symbols have such a universal understanding has also been a subject of research in cognitive science [20]. To show a higher or a more powerful jump, either the same trailing lines on jumping are used, or a strong impact is depicted through stars flying out from the point of impact or a small burst occurring.

Scenario: Running and Jumping. This demo consists of a user being placed in an empty room and encouraged to run and jump around. On running, speed lines appear on the edges of the user's field of view with the aim of conveying faster movement (see Figure 4-7). We chose to use the background lines representation of speed as adding trailing lines was impossible in the first person because we cannot see what is behind us. On jumping and then landing, dust clouds and small explosive effects appear that aim to convey a hard impact to make the user think that they jumped higher or stronger (see Figure 4-4).

Implementation. For this demo we used a Meta Quest Pro headset, which tracked how fast the user was running and when they jumped through its onboard motion tracking. For jump detection we first record the vertical position of a user when they accelerate downwards (i.e., when they bend their knees). We then detected the moment of landing when they again cross that position with downwards velocity (i.e., falling and contacting the ground). An animation is played once a jump landing has been detected.

[4]https://assetstore.unity.com/packages/vfx/particles/epic-toon-fx-57772 and https://assetstore.unity.com/packages/tools/particles-effects/3d-speed-lines-217755

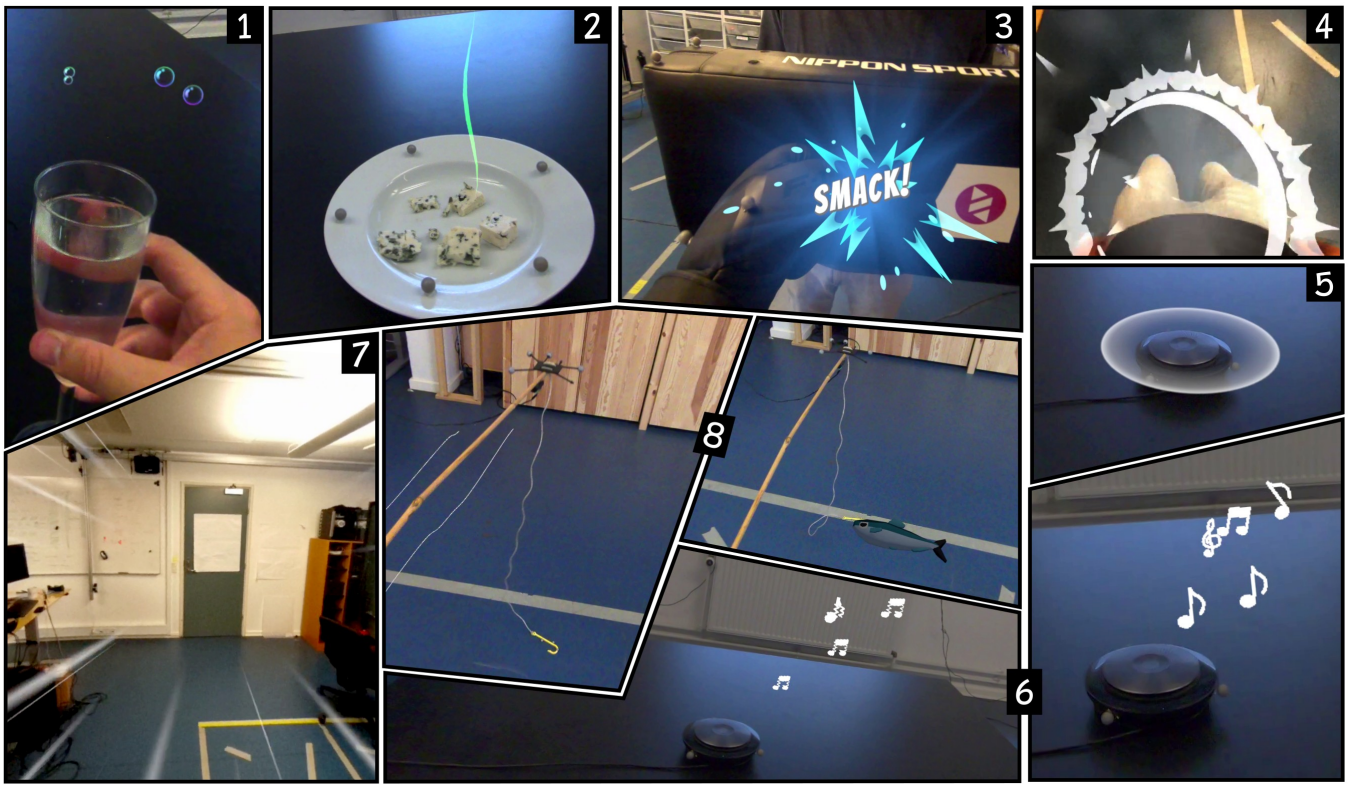

Figure 4: In-headset views of our comic augmentation demos: (1) virtual bubbles on a drink, (2) smell lines on a plate of cheese, (3) hit elements while boxing, (4) ground elements when landing after a jump, (5) pulsing beat animation on a speaker, (6) normal and distorted music notes from a speaker, (7) speed lines while running, and (8) vibration lines on a fishing rod and a virtual fish being caught. Jumping and running from within a Quest Pro, all other from within a Varjo XR-3.

4.3 Augmenting Hearing

Background. Our hearing demo aims to convey enhanced (1) bass and (2) tune of the songs a user is listening to. Comics convey information about the sound coming from a source by emanating visual elements from the speaker. These elements are usually representative of the physical sound waveform or describe the content of the sound, for example, through circular arcs, onomatopoeia, or musical notation. The quality of the sound can also be conveyed by altering these representations themselves, such as an out-of-tune piano or a bad singer being shown with distorted and broken notes around them. This shows that there is something wrong with the sound, just as there is something wrong with the symbols representing it.

Scenario: Music Listening. In this demo users listened to three songs. The first song was a bass-boosted Electronic Dance Music song [5] where we used a circular wave that played at the bass beats to augment the bass (see Figure 4-5). The second song was slightly out-of-tune violin music[6], to which we added distorted music notes to make the music sound worse (see Figure 4-6). The last song was properly tuned violin music[7], to which we added regular music notes to make the music seem more pleasant (see Figure 4-6).

Implementation. We use a Jabra SPEAK 510 MS speaker, with tracking markers placed on the side so as to not disrupt the view of the top from which the symbols emanate. To sync the particle systems for the bass with the music, we hardcode the times at which the particles should play by extracting timestamps of the audio peaks via the Audacity software. For the other two songs the visualization is not synced to the music and we instead generate a stream of notes popping up above the speaker at random intervals, floating up, and fading out.

4.4 Augmenting Taste and Smell

Background. Gustatory experiences can change how food appears to us and tastes, with several examples in HCI of interfaces that manipulate this [98]. Comics also contain a rich visual language of taste and smell, that could potentially serve the same purpose. The two aspects of eating we chose to augment with this demo are smell and texture. Representations of smell in comics are primarily at the extremes—showing us something smells *good* or *bad*. A pie on a window sill with a little swirly stroke on top of it shows it has been freshly baked, while garbage wit thinner, wavy lines (often accompanied by a few flies) illustrates the foul odor. To represent a carbonated drink, comics add bubbles emanating from it. This effect is also used to show that a chemical in a beaker is agitated.

[5] https://www.youtube.com/watch?v=b-8cmhmMrYA
[6] https://www.youtube.com/watch?v=pCseCvorN_A&t=31
[7] https://www.youtube.com/watch?v=y2q7QgtzEJU

Scenario: Cheese and Drink Tasting. For this demo, we aimed to make some cheese taste and smell more intense (see Figure 4-2) and a drink seem fizzier and fancier (see Figure 4-1). For the cheese, this translates to adding "smell lines" to signify that the cheese emits a strong odor and thus also tastes correspondingly strong. For the drink, we add little bubbles that float up from the liquid to make it seem more carbonated.

Implementation. To implement these elements, we attach tracking markers to the plate the cheese is sitting on as well as the bottom of the glass the drink is in. The tracking data is then used in particle systems that generate the wavy lines and the bubbles for the cheese and carbonated drink, respectively. The cheese used was Roquefort and the drink was a lemon soda.

4.5 Augmenting Touch

Background. Our touch demo aims to convey enhanced haptic sensations. We focus on vibrotactile feedback and kinesthetic feedback, which both have common representations in comics. For vibration, these consist of lines around an object representing back-and-forth motion, which can have different variations, such as straight wiggly lines on both sides of an object or multiple arcs around it. For kinesthetic feedback, we focus on impacts that are represented by burst or explosion graphics, sometimes combined with words (such as "WHAM" or "SMASH").

Scenario: Fishing and Boxing. In this fishing game demo the user holds a fishing rod such that its hook rests on the floor. During the game, vibrations on the rod at random intervals conveys that a fish has bitten. Alongside the vibrations, they see lines that are wiggling on both sides of the rod to augment the felt vibrations (see Figure 4-8). As soon as the vibrations are felt and the animation is played, the user has a 0.5 second window to lift the hook up to catch the fish. If successful, a virtual fish appeared on the hook.

For kinesthetic feedback, we created a boxing game that showcases the effect of impact graphics and onomatopoeia. Here, players punch a strike shield bag while wearing boxing gloves. At the time of the hit, we spawn a comic burst and onomatopoeia at the impact location and between the player's hand and the bag (see Figure 4-3). Based on the force applied by the punch, three different onomatopoeia are played, "HIT" for a small amount of force, "SMACK" for medium force, and "KA-POW" for high force. This added visual effect is supposed to enhance the conveyed force of the punch and thus give players the sensation of being more powerful.

Implementation. The user holds a bamboo stick standing in as fishing rod, with a line attached to it that holds a 3D-printed fishing hook. A voice coil actuator (Haptuator Mark II by Tactile Labs) is attached to the rod and provides vibrotactile feedback. For tracking, markers are added to an attachment fixed at the top of the bamboo stick and on the hook. An attachment was used instead of adding markers alongside the rod as markers placed in a straight line have less tracking accuracy. For boxing, tracking markers are added to the strike shield and the gloves. The force of the punch is calculated based on the acceleration of the boxing gloves using the Unity SuperScience[8] set of scripts.

[8]https://github.com/Unity-Technologies/SuperScience

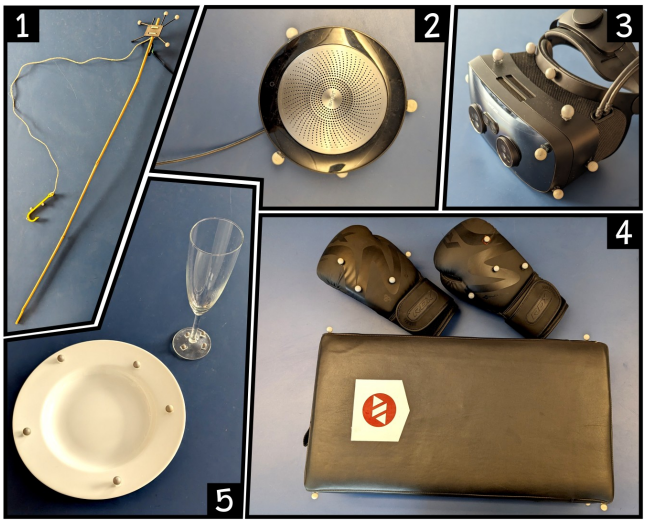

Figure 5: The used study objects with added tracking markers: (1) Fishing rod made of a bamboo stick and 3D printed hook, (2) speaker, (3) Varjo XR-3 headset, (4) boxing gloves, and strike shield, and (5) plate for cheese and glass for the drink.

5 EVALUATING COMIC AUGMENTATIONS

We conducted a user study to test how well and in which ways the visual augmentations convey and enhance non-visual sensations. The study had each participant try out all eight demos, followed by semi-structured interviews about each and the overall experience. The goals of the user study were to: (1) evaluate how our concept of adding comic elements to objects and user actions influences reported perception, (2) understand the effect of combining comic elements with the real world on emotions and user experience, (3) determine design properties of comic elements in augmented reality, and (4) identify applications of our concept that participants imagine to be useful.

5.1 Procedure

First, the experimenter explained that the study involves everyday tasks in AR with added comic-based elements. We did not divulge that we wished to alter sensations so as not to bias the participants. The participants then provided informed consent. We then showed participants the headsets used in the study. They then tried out the Varjo with no augmentation to familiarize themselves with using a headset with video see-through. We followed a relaxed think-aloud protocol [33] for the experiment to enable us to understand the immediate sensation that the participants experienced. After we instructed the participants on verbalizing their thoughts, we asked them to solve a multiplication problem as a warm-up exercise to practice thinking out loud before the actual experiment. Participants then tried the demos in random order. We also randomized the order of songs for the hearing demo. For the fishing demo, the participants wore earplugs to mask the vibration motor's noise, as we only wished for them to focus on the sense of touch. The participants spent at least three minutes with each demo.

Between demos, when we interviewed the participants, they took of the headset. In these short interviews (<5 minutes each) we asked the partiucipants to describe the experience, how the annotations made them feel, and how the interaction was different from normally performing the same action. At the end, we also asked participants about their overall experience with questions related to the impact of the annotations on them, how the tasks felt different from normally performing them, the combination of the real world with comic elements, potential applications, and how they would imagine personalizing the experience. We chose an interview method to collect rich data about the effects of the comic elements instead of settling on a specific rating scale based on our assumptions about the symbols. All interviews were audio recorded and then transcribed (with the otter.ai serice).

5.2 Participants

20 people participated in the study (6 identified as female and 14 as male, mean age 29.4, SD = 5.9). All participants were familiar with the concept of AR. Participants were recruited through posters put up in the university and convenience sampling. Each study session took approximately 45 minutes per participant. At the end of the study, each participant was thanked with a gift worth €20.

5.3 Analysis

We used thematic analysis [92], following an iterative deductive coding approach, to find common trends and define overall themes in the study transcripts. First, data were coded using deductive coding, with four of the authors individually coding the same three interviews in an open coding approach. They then met to discuss and align the codes, resolving discrepancies through discussions, resulting in a set of 10 codes. Subsequently, the remaining 17 interviews were split equally between three of the authors, who coded 2×6 and 1×5 interviews. Furthermore, the lead author also coded all of the interviews to ensure reliable coding. Coding conflicts and new codes during this phase were resolved through discussions with all authors. This led to two codes being added, leading to the final set of 12 codes. All authors then went through the codes and coded lines of the interviews a second time, identifying potential themes while doing so, wihch were then discussed with all authors. Finally, the lead author summarized similar themes.

6 RESULTS

Based on our coded interviews, we describe what effects the comic elements had on participants' perception of sensory elements and their emotions and experiences (Figure 6). We also report their comments on the design and use of the comic elements.

6.1 Perception

All participants reported a boost in their perception with at least one demo, and 11 participants reported a change for at least half of the demos. However, there were large individual differences in how the elements impacted the participants. The most common reasons for these differences (n=18/160) were participants not understanding the meaning of the element or assuming they were in a cartoon or video game world, where the elements would not be reflecting their own capabilities but those of a character they were playing.

6.1.1 Impact on Hearing. Most of the participants (n=15) reported that the music notes enhanced the music. For example, P19 said that *"the violin was still super bad but the notes made it, like, feel worse"* and P9 felt that the notes *"make me judge this person more"*. For the properly tuned violin music, P1 commented that the notes made them *"feel the more classical genre of music"*. P14 reported *"seeing sound"*, and that *"that's funny because it's like in all the classical examples of classical tales of seeing aesthetics like people taking LSD and then being able to see in sounds"*. The notes did not work for some participants who were familiar with sheet music and knew that the notes did not correspond with the music being played, making the elements seem incorrect to them. For instance, P15 stated *"I didn't understand the notes like they should be aligned"*.

The circular elements representing the bass impacted the reported perception of music for 11 participants. However, not all participants mentioned the bass as being enhanced, with participants mentioning that they felt the tempo or the beat of the music more and did not mention the bass. P2 said that it *"intensifies the feeling of the song"*. One participant (P14) thought that the speaker was vibrating when the wave played. The element was interpreted as a regular music visualizer by certain participants, and hence, they did not feel that anything had changed about the music.

6.1.2 Impact on Proprioception. 13 of the participants stated that the speed lines altered their perception of their own speed or their surroundings. P10 stated *"It made me feel like I was going super speed. It made me feel faster!"*, similarly, P1 said *"it looks like you're going very fast, like you like when you sit in the train and things are flying by"*. In some cases, the lines had the opposite effect and participants felt slower, such as P18 interpreting the lines as themselves being faster but the surroundings not moving fast enough, so they felt that they were overall going *"surprisingly slow"*. Some participants interpreted the lines differently, such as P9 thinking that they were getting sucked into a black hole or P14 and P17 interpreting the lines as just strong wind in their faces. The speed lines failed when participants felt that they were over-exaggerating their movement, such as with P6, who only wanted the lines to appear when running at full speed and not just jogging.

The impact dust clouds made some participants feel they were stronger, heavier, or jumped higher (n=7). P4 stated *"So when I landed, it felt like my body had a bit bigger impact on touching the ground than it normally would have"*. P1 thought that along with them being heavier, the floor was more dusty. The effect seeming over-exaggerated was a major cause for participants not feeling a change, with P19 stating that *"I guess that didn't feel realistic that. Okay, I was just barely jumping and I have an impact like that."* When the dust cloud design and a participant's expectations did not align, it also did not have the intended effect. Commenting about the dust clouds not changing based on how high they jumped, P9 said *"it feels like you're just not able to achieve something because the feedback doesn't change. So you feel a bit powerless probably"*.

6.1.3 Impact on Taste and Smell. The bubble on the glass made participants feel that the drink was fizzier, more refreshing, or feel like champagne, even if it was not (n=9). P6 stated *"This is not alcohol, this is Sprite, but it gave me the feeling of having champagne for sure"*, and P9 questioned whether the drink contained alcohol after taking their first sip as *"the bubbles, when they are jumping,*

they cause some associations with being drunk". Unlike P6, when other participants tasted the drink in the glass, they stated it did not feel any different than normal, even if before drinking, they expected it to because of the bubbles. The smell lines on the cheese made several participants believe that the cheese was stinkier than normal or tasted more intense (n=7). P4 said that *"I feel like I tasted more than I would normally"* and P15 felt that *"the cheese is even more smelly than it is"*. Like the bubbles, the effect did not work when participants recognized the cheese as a familiar taste. A few participants also misunderstood the stink lines as heat lines.

6.1.4 Impact on Touch. The impact explosions for the boxing demo made participants feel stronger (n=11). On seeing the explosion, P17 said that *"I caused it with my extremely strong fists!"* and P10 said that their punches *"felt a bit more powerful, stronger"*. The changing visual style of the elements as participants punched harder reinforced the illusion of feeling stronger. For example, P16 stated *"when you would hit harder, the bigger animation would make you feel stronger"*. Some participants primarily relied on the haptic feedback and thus did not feel any different: *"it felt, obviously, that the physical sensation of it was the same"* (P6). The vibration lines on the fishing rods only influenced a few participants (n=4). Most participants ignored the lines to focus only on the vibrotactile feedback to complete the fishing task. Some participants thought the combination of two modalities made them react faster. For example, one participant mentioned *"I think it helps me to like react faster. Because I think lines are sort of like a visual thing that helped me to like detect whether it's like accompanied to the like tactile feedback that you provided."* (P20). P18 thought the elements confirmed that it was not a phantom sensation, *"something is actually going on, you're not just imagining that you feel something"*.

6.1.5 Impact on Attention. Besides causing a change in reported perception, the comic elements impacted the participants' attention. The visuals highlighted objects and actions, encouraging participants to focus their attention on how they feel about them. P13 described the elements as *"it navigates you to to do something like you need to focus your attention here"* and they felt that they were *"focusing more and more on my own feelings"*. P12 said that *"my attention was occupied by this visual effect. So it gives me clear information"* while P6 felt *"much more engrossed into the song"*.

Since the elements had an impact on participant's attention, some found them a hindrance to listening to the actual music, with participants stating that *"I was focusing more on the visual elements, then the actual music"* (P4) and *"If I listen to an involved composition, I like to do that with my eyes closed"* (P18).

6.2 Emotion and Experience

Participants repeatedly described the experiences as fun, joyful, interesting, entertaining, cool, funny, enticing, pleasant, or curious. This effect again varied across people; most really enjoyed it, and for some, the elements also triggered negative feelings such as shame. P5 stated *"It was a little bit more exciting to do things than like, normally"* and P6 described this emotional experience as a missing element in everyday life: *"It's something that's missing. It just brings that spark to everyday life that is otherwise sometimes missing. You can make things count a little bit more."*

6.2.1 Music Enjoyment and Mood. The visual elements of the music made the experience cooler and more fun and added *"some degree of immersion"* (P8) compared to normal music listening. For example, P6 mentioned *"it accentuates the music and the experience one has while listening to music"*. The floating notes felt cozy and calming and made them appreciate the music more: *"those sort of put you into a meditative, relaxed state of mind where you are more dreaming about things"* (P7). In contrast, the bass visualization got them into a party mood, and the jagged notes felt irritating to some participants: *"made me feel irritated. a bit angry, perhaps too"* (P19).

6.2.2 Feeling Like a Superhero. The elements related to the physical activities of running, jumping, and boxing made the participants feel cool and the activity felt more fun: *"I start to have too much fun. I think this is the coolest part"* (P7). Several said that they felt like a superhero, supervillain, cartoon, or anime character, for example, P11 stated *"It's like I'm a superhero who makes this superhero landing"*. Feeling like specific characters such as The Flash, Hulk, and Naruto was mentioned as well. Even if a participant did not report feeling a change in perception, the association of being like a superhero was enough to enhance the user experience. Two participants also found the fishing activity entertaining.

6.2.3 Enhancement of Dining Experience. The elements make the food seem more or less appetizing, an effect similar to how food plating influences the perception of a meal. The bubbles, in particular, made drinking fun, more entertaining, and playful. P20 commented the glass with bubbles *"Looks very yummy"*, while P4 commented the smell lines *"kind of triggered some sort of slight disgust"*. P4 noted that *"when you eat, you actually also eat a lot with your eyes because the presentation and how the food looks can give a whole different dimension of eating."* This effect was again independent of feeling a change in perception with P20 commenting *"I think once I drink the sparkling water, well not the water, the sprite, I don't feel the difference, but once I put it down and see the visualization again, I also want to like a drink it again."*

6.2.4 Motivational Effects. The positive emotional effect of the elements impacted the participant's motivation and encouraged them to engage with the environment or activity. The elements encouraged the participants to do more, the bubbles motivated them to drink more, and they wanted to punch fast and hard, keep jumping and running, or move to the beat of the music. P13 stated *"your instinct is to actually do more, rather than just stop"* and P14 said *"you can influence what's happening, that's motivating."* The elements added to a sense of achievement about their abilities: *"I think these things showed me that I am doing great. So, I think I feel better about myself"* (P11).

6.2.5 Negative Effects. Interestingly, the visual elements could also have the opposite effect on the user's emotions and engagement. When an effect looked "weird," participants had a negative reaction: *"The green light emitting from the cheese made me more reluctant to try to eat it"* (P4). Similarly, P2 and P14 were afraid to try the food because it looked different. In physical activities of punching or jumping, the participants felt sadness and lack of achievement when they could not activate a desirable visual effect. P17 felt embarrassed since the elements were too exaggerated compared to their ability: *"Just made me feel old and out of shape."*

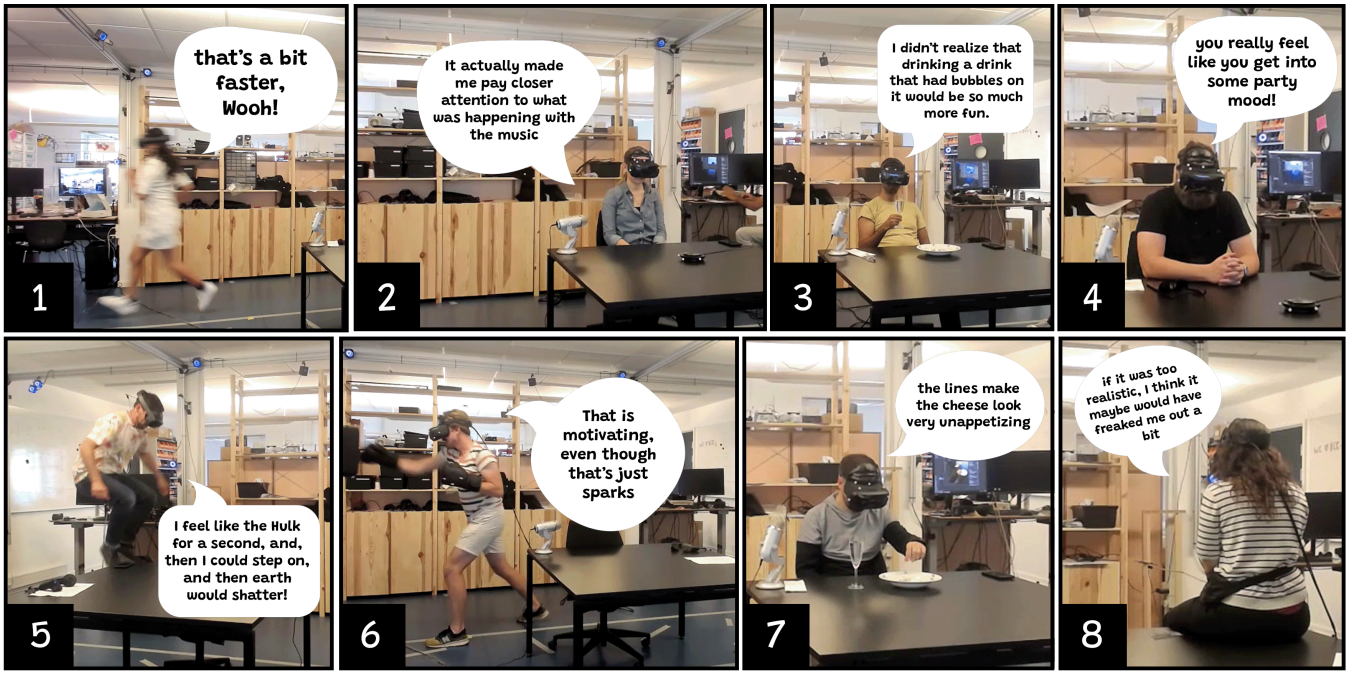

Figure 6: Example scenes from the user study showcasing the participants' comments about the impact of comic AR elements on their perception and attention (1-2), emotion and mood (3-4), making them feel like a superhero (5), motivation (6), and visual appeal of objects (7), as well as the participants' preference for the comic style of the AR elements (8).

6.3 Design Properties

The meaning of the elements was understood correctly by at least 14 participants for all elements except the vibration lines on the fishing rod. We find five main reasons for misinterpretation:

(1) one symbol corresponding to multiple sensations, such as wavy lines for both heat and smell
(2) elements being too subtle or weird, such as the lines on the fishing rod
(3) elements disappearing too quickly for participants to interpret, such as the lines on the fishing rod
(4) correspondence between action and annotation being unbelievable, such as the speed lines appearing while slow jogging and not running at full speed, and
(5) elements being considered solely as visual instead of as sensory information, such as the waves from the speaker being interpreted as a music visualizer instead of sound waves.

The vibration lines seemed to suffer from multiple of the above-mentioned issues and thus were correctly understood by only nine participants but also caused confusion or misunderstanding for an equal number of participants.

6.3.1 Real World vs Comics. When asked about the contrast between the real world and the comic elements, none of the participants thought that it was a problem, and they even preferred the fact that the visuals were not realistic. P1 was *"surprised how natural it felt"* and P19 commented *"that's what made it so enticing because it was so different than the real world"*. Knowing that the elements were not real seemed to contribute to allowing a suspension of disbelief helping cause the change in reported perception: *"so one very cool part to me was that I know it's exaggerated"* (P6). The uncanny valley effect was mentioned by some participants, and they liked that the elements were inspired by comics rather than real-life effects. P12 stated *"I guess this would be a way to avoid uncanny valley in a sense that if they try to resemble the real life, but they do not manage to do so, that will be not super attractive and maybe disturbing but here they were on purpose like cartoonish so yeah I think that's good. Unless something can look really real, authentic, then maybe the cartoon style is better."*

6.3.2 Visual Style. The visual saliency and movement of the effects enhanced or hindered the user's interpretation and experience. Participants noted that the colorful and large effects in the boxing demo made the experience fun and motivated them to punch: *"You want to keep boxing and see the pretty colors"* (P19). In contrast, the vibration lines on the fishing rod were hard to notice, the participants focused on the real vibration. While most participants preferred exaggerated, diverse, and colorful effects, a few wanted the effects to be subtle and *"not in your face"* (P12). Similarly, the 3D nature of the effects and their movements and relation to the user's body raised emotions and curiosity. P18 was positively surprised by the *"3D effect"* of music notes, P16 thought that *"They're so nicely floating"*, and P20 thought the *"weird"* motion of the notes reflected the bad music quality. Some wanted more animation for the music beat. The close proximity of the 3D effects to the user's body played a role: *"interesting when the bubbles pop right in front of my face."* (P18). P17 was similarly excited that the boxing effects were *"exploding from inside the glove"*.

6.3.3 Elements Should Be Interactive. The participants wanted to interact with the visualizations and preferred the effects that reacted to their actions. P14 and P17 tilted the glass and moved the cheese plate to see if the effects responded to the motion. Others moved the glass closer to their face or wanted to poke the bubbles or interact with the musical notes. P9 described how they expected the visuals to react: *"when I touched it, I really wanted [it] to expand, and I think I want to move it"*. When the effects directly changed with their actions, the participants felt engaged. Most participants enjoyed how the visuals in the boxing demo were tightly linked to their actions and body and enjoyed that: *"if you punch harder, it gets like a bigger thing"* (P17). Some participants wanted the jumping effects to similarly react to how hard they jumped.

6.3.4 Tolerance Towards Flaws. The participants accepted some minor inaccuracies in how the visual elements were displayed. For example, although they noticed that the smell lines did not follow the cheese pieces on the plate, most of them stated that they felt an alteration in the smell of cheese (and not the plate). Similarly, some participants thought that the vibration lines on the rod were misaligned: *"Maybe there is some structure on this stick that is not perfectly aligned with the lines"* (P9), but this misalignment did not seem to have an effect on the perception of the vibration. In contrast, misalignments with the property that was the aim of the alteration were more problematic. For example, participants noted that *"those are not right notes"* (P5), indicating that the notes did reflect the music style: *"the notes are crooked, because.. mirroring the music being crooked"* (P18), but not the music itself: *"Interesting that the rate of the appearance does not coincide with the rhythm of the music"* (P14). This also applied to the jumping demo, where participants were distracted when the visual element was not aligned centrally around them or was temporally delayed. P12 commented, *"I think it's cool but the jumping part, it was delayed."*. Some also felt it did not correctly display the impact they thought they would have: *"[...] maybe because I didn't jump high enough. I guess that didn't feel realistic that. Okay, I was just barely jumping and I have the impact like that.* (P19). These observations are in agreement with participants accepting comic-style elements to have an impact in a real situation, meaning that as long as the elements fit with the context, the participants seemed to accept minor deviations in position (for example, the cheese smell lines) or form (for example, the music notes).

6.4 Usage and Applications

Participants were concerned about the overuse of the elements when asked about their opinions on adding comic elements to their everyday lives. They noted that the elements could be distracting, seem gimmicky, and be overstimulating. P13 said: *"if that's going to be all you have, that information coming right straight at your face like it's just maybe too much."* Participants did like the elements however and wanted to have them appear during some tasks, but only if they were used judiciously: *"would be fun to look at it for a while and have it somewhere, but not like all the time"* (P5). They suggested multiple applications where they would like the elements to be used, and we summarize those below.

6.4.1 Entertainment. For the music and food augmentations, participants saw them as useful in a wide range of entertainment locations and activities. This includes concerts, clubs, shows, (dinner) parties, amusement parks, restaurants, and bars. For example, they mentioned *"I could imagine myself being in a fancy restaurant and having a nice ambiance around me created using those visual effects"* (P7). Participants also envisioned new kinds of augmentations for these contexts, such as birthday parties where the kids would love it *"if they saw confetti or sparkles coming out of their cake"* (P10) or augmenting singing by *"some notes that reflect your voice"* (P9). Some participants wished to use the elements similar to how they use music to relax and pass idle time. P7 mentioned that if *"it's a regular boring day and I'm traveling to work and if I have all of these kind of things that I could do to make my daily life more fun."* and P8 suggested: *"if I'm getting back from work really late and just trying to relax completely, I turn it on and then it goes to something happening in the background."*

6.4.2 Movement Learning. Another envisioned application area was movement learning, specifically music and sports, where participants thought the AR comic elements could aid understanding. Discussing the music-related elements, they noted that *"if you're trying to teach someone music, then you can use this like if the person plays some notes and it is offset the note start wobbly and so on and if it knows the notes are correct, then the person who plays it know that he did great"* (P11). For the jumping and boxing elements, they commented the comic elements can help them do the movement correctly: *"if it had a better sense of where my body was, that it could, like, be helpful for training me to land so that I don't hurt my knees when I jump or something like that."* (P17). P11 and P20 made similar comments.

6.4.3 Motivation for Routine Tasks. The motivational power of AR comic effects was the foundation for several applications. In particular, participants thought of sports and chores. For example, P6 noted that the effects could help *"remember more, make them more fun, whether it's like everyday chores or something that you're trying to train towards"*. P11 and P18 made similar comments about cleaning the dishes and doing sports. But as P18 noted the effect can extend beyond motivation *"to improve reaction times."*

7 DISCUSSION

Our findings indicate that comic elements can modify how participants perceive non-visual sensations in AR and make interactions more exciting, playful, and stimulating. Below, we discuss why and how the visual elements can alter experiences, how the results relate to other forms of visual enhancement, and the implications of the results for designing comic-enhanced AR experiences.

7.1 How Comic Elements Modulate Experiences

Experiences are known to consist of "sights and sounds, feelings and thoughts, motives and actions" [32], and our comic elements work by manipulating the aspects that shape an experience.

One reason why the comic augmentations work is because they changed participants' expectations about the objects they engaged

with and the activities they did. Those expectations shape the subsequent interactions, for example, by yielding surprises. The underlying effect—that a first impression alters user experience—is well-known in other areas. For example, Quinn and Tran [75] described how attractive phones are rated higher in usability, altering the user experience based on expectations in a similar way. The effects of expectations are also well studied outside HCI, such as with pain experiences being shaped by expectations [48] and placebo effects, in general [8].

One participant referred to this effect as being "primed", and such priming is also something reported for other interfaces. For example, Nunez and Blake [66] showed how users' presence in VR is affected by them reading more about the virtual environment beforehand. Social priming in VR has also been shown to have a motivating effect on subsequent interactions [65]. Our results are in line with this previous work, further supporting that user experience and behavior can be altered through priming.

Another way the comic elements altered experiences was by complementing user interactions. Experiences are known to draw on all sensations [7], and one sensation can mask, influence, or enhance another [26, 76]. This effect is widely applied in HCI (for example, [64, 91]) and an everyday example of it is using music to enhance workouts [43]. The opposite of this effect also holds, where elements can contrast against user interactions to have detrimental effects on experiences. For example, a participant felt unfit when speed lines appeared at a low jogging speed. Another known phenomenon involving sensory mismatch is motion sickness in virtual reality [15].

7.2 Other Forms of Visual Enhancement

We found several overall effects of visually enhancing activities and experiences, such as making them more enjoyable, exciting, and interesting. These results align with broader previous work that similarly explored how visual and other additions alter how we perceive things. A good example is juicy game design as described by Hicks et al. [35]. Among the visual embellishments they mention are particle and trail effects, which are similar to some of our comic effects. Similar to our results, they found that such visual embellishments improve the player experience, such as with increased hedonic qualities and appeal.

Our participants pointed to sports as a potential application area where the motivating power of comic effects could be useful. In fact, several examples of augmented sports exist that support this application. Noteworthy here is work around climbing where the climbing wall is visually augmented to provide instructions, but also to increase playfulness and add game elements [42]. Visual augmentations can also be more practical and support training, like in the case of Sato et al.'s augmented volleyball [84]. In this case, providing a visual annotation of the ball landing area also increased enjoyment overall. As they point out, the emotional effect is at least partly due to easing the sport for beginners, which supports the notion that aid through visual enhancements can boost motivation for engaging in the sport.

We also found that the interpretation of the content is altered through visual additions, such as when expectations of what is inside a glass change as bubbles are added. Such an effect is reported broadly for other forms of content as well. For example, adding an emoji to a sentence can shift or even flip the meaning of the words [70]. Similarly, our perception of music can change depending on the visual presentation, as noted by Platz and Kopiez [69] in their meta-analysis. The union of music and visuals is closest to the work of the VJ (video jockey), who augments music with their own visual performance. Dekker [21] quotes VJs themselves, who comment on the mood-influencing effects of these visuals.

7.3 Design Implications

Our work informs the design of comic-based AR experiences in two ways. First, the design space of comic elements along the sensation and visual representation dimensions gives designers a quick reference and generative power to incorporate these effects into their applications. Second, our results demonstrate why designers would want to use these effects. Beyond their ability to convey non-visual sensations visually, they can enhance high-level experience, direct attention, affect mood, trigger a suspension of disbelief, and motivate users.

To help designers utilize these effects, our results identify factors that can mediate the effectiveness of these elements. In particular, the diversity and gradation in the effects, close proximity to the user's body, and tight connection to their actions can create compelling effects. Being in the 3D world, users expect the elements to respond to physics laws (such as gravity) and be interactive (such as respond to touch). To increase user engagement, designers can also have the elements show second-order responses to indirect contact and user actions. For instance, shaking a drink before consuming it should impact the number and motion of bubbles. Here, concepts and visual effects from decades of research in games (such as juiciness [36]) can inform the design of these animated responses.

Participants had different interpretations, experiences, and preferences for the effects. To help with interpretation, questionnaires or user data from recommender systems can be used to create elements customized to specific users. Ambiguous elements should be avoided if possible and border effects can be used to make sure the elements are discernible from the background. Animated preview videos and other feedforward techniques [62] could also assist in understanding. Designers should also include customization mechanisms for users to select elements that they understand and tune their visual saliency (including color, size, deviation from reality), frequency, and the timing of the effects. These considerations expand comic AR beyond merely replicating 2D comics into an interactive medium for communication and experience. Given that our comic annotations enhance, emphasize, or change the emotion associated with an action or object similar to how emojis can influence the meaning of a sentence [71], they may have a similar potential for transforming interactions in AR as emojis did through text.

The negative effects observed during our study expose opportunities for harm, and designers should consider the possibilities of misuse and safety hazards when creating comic-enhanced experiences. Organizations might want to use the elements to make their products more attractive and enhance the experience of using them even if they are harmful to the user. This can mislead people

or cause false associations between products and emotions leading to overuse or addiction, similar to how marketing influences people. Given that the elements can also have a negative impact on experience, they can be used in the opposite way to make a competitor's products seem terrible. With their ability to grab attention, the effects can force the user to focus on objects they might not even want to or cause cognitive overload. They can also be distracting, causing users to miss essential cues in their surroundings, and hence should not be used when users need complete vigilance during tasks. Since the elements may alter self-perception, care should be taken such that they do not cause self-esteem and body image issues or make individuals believe they can perform certain physical feats when they cannot, leading to injury. Research on ethics of extended reality technology [11, 24, 95] can further guide these discussions. Compared to other augmented reality techniques, however, our comic-inspired approach to conveying sensations is easily distinguishable from the real world, something which the participants also noted and appreciated. This property can be used to help reduce some of the above-mentioned negative effects and other possibilities for deception.

8 LIMITATIONS AND FUTURE WORK

Our study took place in a lab setting as objects needed to be visible to the tracking cameras at all times, and the Meta Quest Pro imposed a maximum guardian size limit of 15m × 15m and had issues with tracking outdoors. Thus, further developments in tracking technologies are required before this concept can be realized practically for everyday use.

Future studies can further chart the user perception and experience of comic AR elements. Quantitative studies evaluating the perceptual and experiential effects could be run on individual elements to measure the extent of change in user perception or behavior compared to a baseline. Comparisons could be run between different comic elements to find out what works best for the same sensation. Such studies can also explore ways to control the granularity of the degree of change in a sensation is altered by modifying properties such as size, animation style, or color. AR experience designers or game designers can also be involved in such studies to help refine the properties of the individual comic elements. Another avenue will be to examine user perception and experience of the effects over time. With the growing community of XR enthusiasts and hobbyists and rapid advances in body tracking, such studies are increasingly feasible and can provide valuable insights into the utility of comic AR for everyday applications. Furthermore, one can develop a toolkit with a diverse set of comic AR elements from the design space to facilitate the integration of these elements into AR applications for researchers and practitioners.

Our work focused on senses relevant to AR, but the manipulation of other sensations outside our technological reach can be explored in the future. Can we use comic effects to not just alter sensations related to actions and objects but also the internal state of our bodies[22]? The need to puke is represented as the face turning green or the cheeks turning larger and could this actually make a person want to puke? Can birds flying around the head or the eyes turning spiral make a person believe they are confused? A challenge with these effects is that users do not see their own faces while wearing an AR headset, but their image on reflective surfaces could be a way to achieve these effects.

The comic elements in our study appear before or during an interaction, and a further possibility could also be elements appearing after actions. Comic effects could be applied to the environment after a user finishes as an action to change perception. For example, a halo appears on top of a user's head after recycling to keep them motivated to do so.

While comics are static and the world is dynamic, we use comics as our source of inspiration over animation. We only wished to annotate objects and actions but not change how we move or behave as done in animation [93]. With advances in tracking and generative artificial intelligence, future work can manipulate objects and people in new, unconventional ways. For example, the animation principle of "squash and stretch" could be applied to the fist instead of our comic bursts to achieve the same effect of perceiving the hit to be harder than it is.

Finally, our focus with this work was on an individual's experience. Future work can explore how these effects impact social interactions among users such as sports or social gatherings. Similar representations of emotions through emanata are an obvious extension of the concept. Also, some comic elements in the design space are not suitable for first-person view (such as trailing lines) but can be effective when applied to the actions of other people. For example, in group settings, how do people perceive others when people apply different kinds of comic elements to themselves? Can gold elements make someone feel sophisticated? Future studies can answer such questions to further inform the use of comic elements for collaborative settings.

9 CONCLUSION

We have presented a design space and evaluation of AR comic elements for augmenting objects and activities to convey non-visual sensations and enhance everyday experiences. Drawing on the visual language of comics, we have identified a set of visual elements that are suitable for use in an AR scenario. Our design space demonstrates how elements can be used to convey sensations and, thus, can serve as a reference for researchers and designers to help them convey non-visual sensations in AR. Through eight demos, we have illustrated the feasibility of such effects, and we have shown their effectiveness through a qualitative evaluation. Our results point to a wide range of applications for this form of augmentation, such as in sports or entertainment. Comic effects have the potential to enhance everyday activities to make them more engaging and to influence users' attention, expectations, and behaviors.

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REFERENCES

[1] Daniel Andrews, Chris Baber, Sergey Efremov, and Mikhail Komarov. 2012. Creating and using interactive narratives: reading and writing branching comics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI '12)*. Association for Computing Machinery, New York, NY, USA, 1703–1712. https://doi.org/10.1145/2207676.2208298

[2] Toshiki Aoki, Rintaro Chujo, Katsufumi Matsui, Saemi Choi, and Ari Hautasaari. 2022. EmoBalloon - Conveying Emotional Arousal in Text Chats with Speech Balloons. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)*. Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3491102.3501920

[3] Kohei Arai and Herman Tolle. 2011. Method for real time text extraction of digital manga comic. *International Journal of Image Processing (IJIP)* 4, 6 (2011), 669–676.

[4] Olivier Augereau, Motoi Iwata, and Koichi Kise. 2018. A Survey of Comics Research in Computer Science. *Journal of Imaging* 4, 7 (July 2018), 87. https://doi.org/10.3390/jimaging4070087 Number: 7 Publisher: Multidisciplinary Digital Publishing Institute.

[5] Mahdi Azmandian, Mark Hancock, Hrvoje Benko, Eyal Ofek, and Andrew D. Wilson. 2016. Haptic Retargeting: Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1968–1979. https://doi.org/10.1145/2858036.2858226

[6] Yuki Ban, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. 2013. Modifying perceived size of a handled object through hand image deformation. *Presence: Teleoperators and Virtual Environments* 22, 3 (2013), 255–270.

[7] Lisa Feldman Barrett. 2017. The theory of constructed emotion: an active inference account of interoception and categorization. *Social cognitive and affective neuroscience* 12, 1 (2017), 1–23.

[8] Henry K Beecher. 1955. The powerful placebo. *Journal of the American Medical Association* 159, 17 (1955), 1602–1606.

[9] M. Billinghurst, H. Kato, and I. Poupyrev. 2001. The MagicBook - moving seamlessly between reality and virtuality. *IEEE Computer Graphics and Applications* 21, 3 (2001), 6–8. https://doi.org/10.1109/38.920621

[10] Andreea Dalia Blaga, Maite Frutos-Pascual, Chris Creed, and Ian Williams. 2020. Too Hot to Handle: An Evaluation of the Effect of Thermal Visual Representation on User Grasping Interaction in Virtual Reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3313831.3376554

[11] Elise Bonnail, Wen-Jie Tseng, Mark Mcgill, Eric Lecolinet, Samuel Huron, and Jan Gugenheimer. 2023. Memory Manipulations in Extended Reality. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 875, 20 pages. https://doi.org/10.1145/3544548.3580988

[12] Felix Born, Adrian Rygula, and Maic Masuch. 2021. Motivating Players to Perform an Optional Strenuous Activity in a Virtual Reality Exergame Using Virtual Performance Augmentation. *Proceedings of the ACM on Human-Computer Interaction* 5, CHI PLAY (Oct. 2021), 225:1–225:21. https://doi.org/10.1145/3474652

[13] Ying Cao, Rynson W. H. Lau, and Antoni B. Chan. 2014. Look over Here: Attention-Directing Composition of Manga Elements. *ACM Trans. Graph.* 33, 4, Article 94 (jul 2014), 11 pages. https://doi.org/10.1145/2601097.2601183

[14] Julien Cauquis, Victor Rodrigo Mercado, Géry Casiez, Jean-Marie Normand, and Anatole Lécuyer. 2022. "Kapow!": Studying the Design of Visual Feedback for Representing Contacts in Extended Reality. In *Proceedings of the 28th ACM Symposium on Virtual Reality Software and Technology (VRST '22)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3562939.3565607

[15] Eunhee Chang, Hyun Taek Kim, and Byounghyun Yoo. 2020. Virtual reality sickness: a review of causes and measurements. *International Journal of Human–Computer Interaction* 36, 17 (2020), 1658–1682.

[16] Yi Fei Cheng, Hang Yin, Yukang Yan, Jan Gugenheimer, and David Lindlbauer. 2022. Towards Understanding Diminished Reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 549, 16 pages. https://doi.org/10.1145/3491102.3517452

[17] Wei-Ta Chu and Wei-Chung Cheng. 2016. Manga-specific features and latent style model for manga style analysis. In *2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE, IEEE, Los Alamitos, CA, USA, 1332–1336.

[18] Neil Cohn. 2013. *The Visual Language of Comics: Introduction to the Structure and Cognition of Sequential Images*. Bloomsbury, London, United Kingdom.

[19] Neil Cohn and Sean Ehly. 2016. The vocabulary of manga: Visual morphology in dialects of Japanese Visual Language. *Journal of Pragmatics* 92 (2016), 17–29. https://doi.org/10.1016/j.pragma.2015.11.008

[20] Neil Cohn and Stephen Maher. 2015. The notion of the motion: The neurocognition of motion lines in visual narratives. *Brain Research* 1601 (2015), 73–84. https://doi.org/10.1016/j.brainres.2015.01.018

[21] Annet Dekker. 2005. VJ Culture: A Phenomenon in History, Presentation, and Perception. http://vjcultuur.nl/vjculturereportEnglish.pdf

[22] Christopher Eccleston. 2016. *Embodied: the psychology of physical sensation*. Oxford University Press, Kettering, UK.

[23] Daniel Eckhoff, Christian Sandor, Gladys L. Y. Cheing, Jan Schnupp, and Alvaro Cassinelli. 2022. Thermal pain and detection threshold modulation in augmented reality. *Frontiers in Virtual Reality* 3 (2022), 952637. https://doi.org/10.3389/frvir.2022.952637

[24] Chloe Eghtebas, Gudrun Klinker, Susanne Boll, and Marion Koelle. 2023. Co-Speculating on Dark Scenarios and Unintended Consequences of a Ubiquitous(Ly) Augmented Reality. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference* (Pittsburgh, PA, USA) *(DIS '23)*. Association for Computing Machinery, New York, NY, USA, 2392–2407. https://doi.org/10.1145/3563657.3596073

[25] Will Eisner. 2008. *Comics and sequential art: Principles and practices from the legendary cartoonist*. WW Norton & Company, New York, NY, USA.

[26] Marc O Ernst and Martin S Banks. 2002. Humans integrate visual and haptic information in a statistically optimal fashion. *Nature* 415, 6870 (2002), 429–433.

[27] Thibault Fabre, Adrien Verhulst, Alfonso Balandra, Maki Sugimoto, and Masahiko Inami. 2021. Investigating Textual Visual Sound Effects in a Virtual Environment and their impacts on Object Perception and Sound Perception. In *2021 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, Los Alamitos, CA, USA, 320–328. https://doi.org/10.1109/ISMAR52148.2021.00048

[28] Wilson S Geisler. 1999. Motion streaks provide a spatial code for motion direction. *Nature* 400, 6739 (1999), 65–69.

[29] Antti Granqvist, Tapio Takala, Jari Takatalo, and Perttu Hämäläinen. 2018. Exaggeration of Avatar Flexibility in Virtual Reality. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play* (Melbourne, VIC, Australia) *(CHI PLAY '18)*. Association for Computing Machinery, New York, NY, USA, 201–209. https://doi.org/10.1145/3242671.3242694

[30] Nazim Haouchine, Winnie Kuang, Stephane Cotin, and Michael Yip. 2018. Vision-Based Force Feedback Estimation for Robot-Assisted Surgery Using Instrument-Constrained Biomechanical Three-Dimensional Maps. *IEEE Robotics and Automation Letters* 3, 3 (2018), 2160–2165. https://doi.org/10.1109/LRA.2018.2810948

[31] Satoshi Hashiguchi, Shohei Mori, Miho Tanaka, Fumihisa Shibata, and Asako Kimura. 2018. Perceived weight of a rod under augmented and diminished reality visual effects. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology*. Association for Computing Machinery, New York, NY, USA, 1–6.

[32] Marc Hassenzahl. 2010. *Experience design: Technology for all the right reasons*. Morgan & Claypool Publishers, Kentfield, CA, USA.

[33] Morten Hertzum, Pia Borlund, and Kristina B. Kristoffersen. 2015. What Do Thinking-Aloud Participants Say? A Comparison of Moderated and Unmoderated Usability Sessions. *International Journal of Human–Computer Interaction* 31, 9 (2015), 557–570. https://doi.org/10.1080/10447318.2015.1065691

[34] Anuruddha Hettiarachchi and Daniel Wigdor. 2016. Annexing Reality: Enabling Opportunistic Use of Everyday Objects as Tangible Proxies in Augmented Reality. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1957–1967. https://doi.org/10.1145/2858036.2858134

[35] Kieran Hicks, Kathrin Gerling, Patrick Dickinson, and Vero Vanden Abeele. 2019. Juicy Game Design: Understanding the Impact of Visual Embellishments on Player Experience. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Barcelona, Spain) *(CHI PLAY '19)*. Association for Computing Machinery, New York, NY, USA, 185–197. https://doi.org/10.1145/3311350.3347171

[36] Kieran Hicks, Kathrin Gerling, Graham Richardson, Tom Pike, Oliver Burman, and Patrick Dickinson. 2019. Understanding the Effects of Gamification and Juiciness on Players. In *2019 IEEE Conference on Games (CoG)*. IEEE, Los Alamitos, CA, USA, 1–8. https://doi.org/10.1109/CIG.2019.8848105

[37] Yuichi Hirano, Asako Kimura, Fumihisa Shibata, and Hideyuki Tamura. 2011. Psychophysical influence of mixed-reality visual stimulation on sense of hardness. In *2011 IEEE virtual reality conference*. IEEE, IEEE, Los Alamitos, CA, USA, 51–54.

[38] Ludovic Hoyet, Ferran Argelaguet, Corentin Nicole, and Anatole Lécuyer. 2016. "Wow! I Have Six Fingers!": Would You Accept Structural Changes of Your Hand in VR? *Frontiers in Robotics and AI* 3, 27 (2016), 27. https://doi.org/10.3389/frobt.2016.00027

[39] Christos Ioannou, Patrick Archard, Eamonn O'Neill, and Christof Lutteroth. 2019. Virtual Performance Augmentation in an Immersive Jump & Run Exergame. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3290605.3300388

[40] Junko Itou, Kazuho Matsumura, Jun Munemori, and Noboru Babaguchi. 2019. A Comic-Style Chat System with Japanese Expression Techniques for More Expressive Communication. In *Collaboration Technologies and Social Computing (Lecture Notes in Computer Science)*, Hideyuki Nakanishi, Hironori Egi, Irene-Angelica Chounta, Hideyuki Takada, Satoshi Ichimura, and Ulrich Hoppe (Eds.). Springer International Publishing, Cham, 172–187. https://doi.org/10.1007/978-3-030-28011-6_12

[41] Inyoung Jang and Dongjun Lee. 2014. On utilizing pseudo-haptics for cutaneous fingertip haptic device. In *2014 IEEE Haptics Symposium (HAPTICS)*. IEEE, Los Alamitos, CA, USA, 635–639. https://doi.org/10.1109/HAPTICS.2014.6775529

[42] Raine Kajastila, Leo Holsti, and Perttu Hämäläinen. 2016. The Augmented Climbing Wall: High-Exertion Proximity Interaction on a Wall-Sized Interactive Surface. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 758–769. https://doi.org/10.1145/2858036.2858450

[43] Costas I Karageorghis and David-Lee Priest. 2012. Music in the exercise domain: a review and synthesis (Part I). *International review of sport and exercise psychology* 5, 1 (2012), 44–66.

[44] Rubaiat Habib Kazi, Tovi Grossman, Cory Mogk, Ryan Schmidt, and George Fitzmaurice. 2016. ChronoFab: Fabricating Motion. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 908–918. https://doi.org/10.1145/2858036.2858138

[45] Jonathan Kipnis. 2018. Immune system: The "seventh sense". *Journal of experimental medicine* 215, 2 (2018), 397–398.

[46] Rebecca Kleinberger, Akito Oshiro Van Troyer, and Qian Janice Wang. 2023. Auditory Seasoning Filters: Altering Food Perception via Augmented Sonic Feedback of Chewing Sounds. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 318, 15 pages. https://doi.org/10.1145/3544548.3580755

[47] Martin Kocur, Melanie Kloss, Valentin Schwind, Christian Wolff, and Niels Henze. 2020. Flexing Muscles in Virtual Reality: Effects of Avatars' Muscular Appearance on Physical Performance. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Virtual Event, Canada) *(CHI PLAY '20)*. Association for Computing Machinery, New York, NY, USA, 193–205. https://doi.org/10.1145/3410404.3414261

[48] Tetsuo Koyama, John G. McHaffie, Paul J. Laurienti, and Robert C. Coghill. 2005. The subjective experience of pain: Where expectations become reality. *Proceedings of the National Academy of Sciences* 102, 36 (2005), 12950–12955. https://doi.org/10.1073/pnas.0408576102

[49] Eike Langbehn, Tino Raupp, Gerd Bruder, Frank Steinicke, Benjamin Bolte, and Markus Lappe. 2016. Visual blur in immersive virtual environments: does depth of field or motion blur affect distance and speed estimation?. In *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology (VRST '16)*. Association for Computing Machinery, New York, NY, USA, 241–250. https://doi.org/10.1145/2993369.2993379

[50] Klemen Lilija, Henning Pohl, Sebastian Boring, and Kasper Hornbæk. 2019. Augmented Reality Views for Occluded Interaction. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300676

[51] Markus Löchtefeld, Antonio Krüger, and Hans Gellersen. 2016. DeceptiBike: Assessing the Perception of Speed Deception in a Virtual Reality Training Bike System. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction (NordiCHI '16)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/2971485.2971513

[52] Fiona Macpherson. 2011. Taxonomising the Senses. *Philosophical Studies* 153, 1 (2011), 123–142. https://doi.org/10.1007/s11098-010-9643-8

[53] Mizuki Matsubara, Olivier Augereau, Charles Lima Sanches, and Koichi Kise. 2016. Emotional arousal estimation while reading comics based on physiological signal analysis. In *Proceedings of the 1st International Workshop on comics ANalysis, Processing and Understanding*. Association for Computing Machinery, New York, NY, USA, 1–4.

[54] Scott McCloud. 2006. *Making comics: Storytelling secrets of comics, manga and graphic novels.* Harper New York, New York, NY, USA.

[55] Scott McCloud and AD Manning. 1998. Understanding comics: The invisible art. *IEEE Transactions on Professional Communications* 41, 1 (1998), 66–69.

[56] Scott McLoud. 2000. *Reinventing comics: How imagination and technology are revolutionizing an art form.* Perennial, New York, New York, NY, USA. 118–122 pages.

[57] Sebastian Misztal, Guillermo Carbonell, and Jonas Schild. 2020. Visual Delegates - Enhancing Player Perception by Visually Delegating Player Character Sensation. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Virtual Event, Canada) *(CHI PLAY '20)*. Association for Computing Machinery, New York, NY, USA, 386–399. https://doi.org/10.1145/3410404.3414238

[58] Sebastian Misztal, Guillermo Carbonell, Lysann Zander, and Jonas Schild. 2020. Intensifying Stress Perception Using Visual Effects in VR Games. In *Proceedings of the 15th International Conference on the Foundations of Digital Games* (Bugibba, Malta) *(FDG '20)*. Association for Computing Machinery, New York, NY, USA, Article 58, 4 pages. https://doi.org/10.1145/3402942.3409781

[59] Sebastian Misztal and Jonas Schild. 2022. Visual Delegate Generalization Frame – Evaluating Impact of Visual Effects and Elements on Player and User Experiences in Video Games and Interactive Virtual Environments. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 191, 20 pages. https://doi.org/10.1145/3491102.3501885

[60] Sebastian Misztal, Anna Tarrach, Madeline Ebeling, Artur Ritter, and Jonas Schild. 2022. Visualizing Perceptions of Non-Player Characters in Interactive Virtual Reality Environments. In *Proceedings of the 28th ACM Symposium on Virtual Reality Software and Technology* (Tsukuba, Japan) *(VRST '22)*. Association for Computing Machinery, New York, NY, USA, Article 84, 2 pages. https://doi.org/10.1145/3562939.3565680

[61] Yann Moullec, Justine Saint-Aubert, Julien Manson, Mélanie Cogné, and Anatole Lécuyer. 2022. Multi-sensory display of self-avatar's physiological state: virtual breathing and heart beating can increase sensation of effort in VR. *IEEE Transactions on Visualization and Computer Graphics* 28, 11 (Nov. 2022), 3596–3606. https://doi.org/10.1109/TVCG.2022.3203120 Conference Name: IEEE Transactions on Visualization and Computer Graphics.

[62] Andreea Muresan, Jess Mcintosh, and Kasper Hornbæk. 2023. Using Feedforward to Reveal Interaction Possibilities in Virtual Reality. *ACM Trans. Comput.-Hum. Interact.* 30, 6, Article 82 (sep 2023), 47 pages. https://doi.org/10.1145/3603623

[63] S. C. Mölbert, A. Thaler, B. J. Mohler, S. Streuber, J. Romero, M. J. Black, S. Zipfel, H.-O. Karnath, and K. E. Giel. 2018. Assessing body image in anorexia nervosa using biometric self-avatars in virtual reality: Attitudinal components rather than visual body size estimation are distorted. *Psychological Medicine* 48, 4 (2018), 642–653. https://doi.org/10.1017/S0033291717002008

[64] Takuji Narumi, Yusuke Ujitoko, Yuki Ban, Tomohiro Tanikawa, Koichi Hirota, and Michitaka Hirose. 2017. Resistive swipe: Visuo-haptic interaction during swipe gestures to scroll background images on touch interfaces. In *2017 IEEE World Haptics Conference (WHC)*. IEEE, IEEE, Los Alamitos, CA, USA, 334–339.

[65] Nahal Norouzi, Matthew Gottsacker, Gerd Bruder, Pamela J. Wisniewski, Jeremy Bailenson, and Greg Welch. 2022. Virtual Humans with Pets and Robots: Exploring the Influence of Social Priming on One's Perception of a Virtual Human. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, Los Alamitos, CA, USA, 311–320. https://doi.org/10.1109/VR51125.2022.00050

[66] David Nunez and Edwin Blake. 2003. Conceptual Priming as a Determinant of Presence in Virtual Environments. In *Proceedings of the 2nd International Conference on Computer Graphics, Virtual Reality, Visualisation and Interaction in Africa* (Cape Town, South Africa) *(AFRIGRAPH '03)*. Association for Computing Machinery, New York, NY, USA, 101–108. https://doi.org/10.1145/602330.602350

[67] Jiwon Oh and Gerard J. Kim. 2019. The Effect of Onomatopoeia to Enhancing User Experience in Virtual Reality. In *Virtual, Augmented and Mixed Reality. Multimodal Interaction*, Jessie Y.C. Chen and Gino Fragomeni (Eds.). Springer International Publishing, Cham, 143–152.

[68] Ivelina V. Piryankova, Hong Yu Wong, Sally A. Linkenauger, Catherine Stinson, Matthew R. Longo, Heinrich H. Bülthoff, and Betty J. Mohler. 2014. Owning an Overweight or Underweight Body: Distinguishing the Physical, Experienced and Virtual Body. *PLOS ONE* 9, 8 (08 2014), 1–13. https://doi.org/10.1371/journal.pone.0103428

[69] Friedrich Platz and Reinhard Kopiez. 2012. When the Eye Listens: A Meta-analysis of How Audio-visual Presentation Enhances the Appreciation of Music Performance. *Music Perception* 30, 1 (09 2012), 71–83. https://doi.org/10.1525/mp.2012.30.1.71

[70] Henning Pohl, Christian Domin, and Michael Rohs. 2017. Beyond Just Text: Semantic Emoji Similarity Modeling to Support Expressive Communication. *ACM Trans. Comput.-Hum. Interact.* 24, 1, Article 6 (mar 2017), 42 pages. https://doi.org/10.1145/3039685

[71] Henning Pohl, Christian Domin, and Michael Rohs. 2017. Beyond Just Text: Semantic Emoji Similarity Modeling to Support Expressive Communication. *ACM Trans. Comput.-Hum. Interact.* 24, 1, Article 6 (mar 2017), 42 pages. https://doi.org/10.1145/3039685

[72] Michael I Posner, Mary J Nissen, and Raymond M Klein. 1976. Visual dominance: an information-processing account of its origins and significance. *Psychological review* 83, 2 (1976), 157.

[73] Parinya Punpongsanon, Daisuke Iwai, and Kosuke Sato. 2015. Softar: Visually manipulating haptic softness perception in spatial augmented reality. *IEEE transactions on visualization and computer graphics* 21, 11 (2015), 1279–1288.

[74] Yingge Qu, Tien-Tsin Wong, and Pheng-Ann Heng. 2006. Manga Colorization. *ACM Trans. Graph.* 25, 3 (jul 2006), 1214–1220. https://doi.org/10.1145/1141911.1142017

[75] Jeffrey M. Quinn and Tuan Q. Tran. 2010. Attractive Phones Don't Have to Work Better: Independent Effects of Attractiveness, Effectiveness, and Efficiency on Perceived Usability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. Association for

Computing Machinery, New York, NY, USA, 353–362. https://doi.org/10.1145/1753326.1753380

[76] Sharif Razzaque, Zachariah Kohn, and Mary C. Whitton. 2001. Redirected Walking. In *22nd Annual Conference of the European Association for Computer Graphics, Eurographics 2001 - Short Presentations, Manchester, UK, September 3-7, 2001*, Jonathan C. Roberts (Ed.). Eurographics Association, Eindhoven, The Netherlands, 6. https://doi.org/10.2312/EGS.20011036

[77] Catherine L. Reed and Mounia Ziat. 2018. Haptic Perception: From the Skin to the Brain. In *Reference Module in Neuroscience and Biobehavioral Psychology*. Elsevier, Amsterdam, Netherlands. https://doi.org/10.1016/B978-0-12-809324-5.03182-5

[78] Carol E. Reiley, Takintope Akinbiyi, Darius Burschka, David C. Chang, Allison M. Okamura, and David D. Yuh. 2008. Effects of visual force feedback on robot-assisted surgical task performance. *The Journal of Thoracic and Cardiovascular Surgery* 135, 1 (2008), 196–202. https://doi.org/10.1016/j.jtcvs.2007.08.043

[79] Michael Rietzler, Florian Geiselhart, Julian Frommel, and Enrico Rukzio. 2018. Conveying the Perception of Kinesthetic Feedback in Virtual Reality Using State-of-the-Art Hardware. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3174034

[80] Michael Rietzler, Gabriel Haas, Thomas Dreja, Florian Geiselhart, and Enrico Rukzio. 2019. Virtual Muscle Force: Communicating Kinesthetic Forces Through Pseudo-Haptic Feedback and Muscle Input. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) *(UIST '19)*. Association for Computing Machinery, New York, NY, USA, 913–922. https://doi.org/10.1145/3332165.3347871

[81] Jan Ole Rixen, Teresa Hirzle, Mark Colley, Yannick Etzel, Enrico Rukzio, and Jan Gugenheimer. 2021. Exploring Augmented Visual Alterations in Interpersonal Communication. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 730, 11 pages. https://doi.org/10.1145/3411764.3445597

[82] Shadan Sadeghian and Marc Hassenzahl. 2021. From Limitations to "Superpowers": A Design Approach to Better Focus on the Possibilities of Virtual Reality to Augment Human Capabilities. In *Proceedings of the 2021 ACM Designing Interactive Systems Conference* (Virtual Event, USA) *(DIS '21)*. Association for Computing Machinery, New York, NY, USA, 180–189. https://doi.org/10.1145/3461778.3462111

[83] Majed Samad, Elia Gatti, Anne Hermes, Hrvoje Benko, and Cesare Parise. 2019. Pseudo-Haptic Weight: Changing the Perceived Weight of Virtual Objects By Manipulating Control-Display Ratio. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300550

[84] Koya Sato, Yuji Sano, Mai Otsuki, Mizuki Oka, and Kazuhiko Kato. 2019. Augmented Recreational Volleyball Court: Supporting the Beginners' Landing Position Prediction Skill by Providing Peripheral Visual Feedback. In *Proceedings of the 10th Augmented Human International Conference 2019* (Reims, France) *(AH2019)*. Association for Computing Machinery, New York, NY, USA, Article 15, 9 pages. https://doi.org/10.1145/3311823.3311843

[85] Valentin Schwind, Pascal Knierim, Lewis Chuang, and Niels Henze. 2017. "Where's Pinky?": The Effects of a Reduced Number of Fingers in Virtual Reality. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Amsterdam, The Netherlands) *(CHI PLAY '17)*. Association for Computing Machinery, New York, NY, USA, 507–515. https://doi.org/10.1145/3116595.3116596

[86] Valentin Schwind, Pascal Knierim, Cagri Tasci, Patrick Franczak, Nico Haas, and Niels Henze. 2017. "These Are Not My Hands!": Effect of Gender on the Perception of Avatar Hands in Virtual Reality. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 1577–1582. https://doi.org/10.1145/3025453.3025602

[87] Tanay Singhal and Oliver Schneider. 2021. Juicy Haptic Design: Vibrotactile Embellishments Can Improve Player Experience in Games. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 126, 11 pages. https://doi.org/10.1145/3411764.3445463

[88] Richard Sorabji. 1971. Aristotle on Demarcating the Five Senses. *The Philosophical Review* 80, 1 (1971), 55–79. http://www.jstor.org/stable/2184311

[89] Maximilian Speicher, Brian D. Hall, and Michael Nebeling. 2019. What is Mixed Reality?. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3290605.3300767

[90] Yuki Taima, Yuki Ban, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. 2014. Controlling fatigue while lifting objects using pseudo-haptics in a mixed reality space. In *2014 IEEE Haptics Symposium (HAPTICS)*. IEEE, IEEE, Los Alamitos, CA, USA, 175–180.

[91] Ana Tajadura-Jiménez, Maria Basia, Ophelia Deroy, Merle Fairhurst, Nicolai Marquardt, and Nadia Bianchi-Berthouze. 2015. As Light as Your Footsteps: Altering Walking Sounds to Change Perceived Body Weight, Emotional State and Gait. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 2943–2952. https://doi.org/10.1145/2702123.2702374

[92] Gareth Terry, Nikki Hayfield, Victoria Clarke, and Virginia Braun. 2017. Thematic analysis. *The SAGE handbook of qualitative research in psychology* 2 (2017), 17–37.

[93] Frank Thomas and Ollie Johnston. 1995. *The illusion of life: Disney animation*. Hyperion, New York, NY, USA.

[94] Tanh Quang Tran, Thanh Dat Ngoc Tran, Tam Duy Nguyen, Holger Regenbrecht, and Minh-Triet Tran. 2018. Can we perceive changes in our moving speed: a comparison between directly and indirectly powering the locomotion in virtual environments. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology (VRST '18)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3281505.3281510

[95] Wen-Jie Tseng, Elise Bonnail, Mark McGill, Mohamed Khamis, Eric Lecolinet, Samuel Huron, and Jan Gugenheimer. 2022. The Dark Side of Perceptual Manipulations in Virtual Reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 612, 15 pages. https://doi.org/10.1145/3491102.3517728

[96] Yusuke Ujitoko and Yuki Ban. 2021. Survey of pseudo-haptics: Haptic feedback design and application proposals. *IEEE Transactions on Haptics* 14, 4 (2021), 699–711.

[97] Robert J Van Beers, Anne C Sittig, and Jan J Denier van der Gon. 1999. Integration of proprioceptive and visual position-information: An experimentally supported model. *Journal of neurophysiology* 81, 3 (1999), 1355–1364.

[98] Chi Thanh Vi, Damien Ablart, Daniel Arthur, and Marianna Obrist. 2017. Gustatory Interface: The Challenges of 'How' to Stimulate the Sense of Taste. In *Proceedings of the 2nd ACM SIGCHI International Workshop on Multisensory Approaches to Human-Food Interaction* (Glasgow, UK) *(MHFI 2017)*. Association for Computing Machinery, New York, NY, USA, 29–33. https://doi.org/10.1145/3141788.3141794

[99] Mort Walker. 1980. *The lexicon of comicana*. iUniverse, Bloomington, IN, USA.

[100] Yan Wang, Zhuying Li, Robert S. Jarvis, Joseph La Delfa, Rohit Ashok Khot, and Florian Floyd Mueller. 2020. WeScream! Toward Understanding the Design of Playful Social Gustosonic Experiences with Ice Cream. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference* (Eindhoven, Netherlands) *(DIS '20)*. Association for Computing Machinery, New York, NY, USA, 951–963. https://doi.org/10.1145/3357236.3395456

[101] Yan Wang, Zhuying Li, Robert S. Jarvis, Angelina Russo, Rohit Ashok Khot, and Florian 'Floyd' Mueller. 2019. Towards Understanding the Design of Playful Gustosonic Experiences with Ice Cream. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Barcelona, Spain) *(CHI PLAY '19)*. Association for Computing Machinery, New York, NY, USA, 239–251. https://doi.org/10.1145/3311350.3347194

[102] Yan Wang, Zhuying Li, Rohit Ashok Khot, and Florian Floyd Mueller. 2021. Sonic Straws: A Beverage-Based Playful Gustosonic System. In *Adjunct Proceedings of the 2021 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2021 ACM International Symposium on Wearable Computers* (Virtual, USA) *(UbiComp '21)*. Association for Computing Machinery, New York, NY, USA, 81–82. https://doi.org/10.1145/3460418.3479293

[103] Wesley Willett, Bon Adriel Aseniero, Sheelagh Carpendale, Pierre Dragicevic, Yvonne Jansen, Lora Oehlberg, and Petra Isenberg. 2022. Perception! Immersion! Empowerment! Superpowers as Inspiration for Visualization. *IEEE Transactions on Visualization and Computer Graphics* 28, 1 (2022), 22–32. https://doi.org/10.1109/TVCG.2021.3114844

[104] Dennis Wolf, Katja Rogers, Christoph Kunder, and Enrico Rukzio. 2020. JumpVR: Jump-Based Locomotion Augmentation for Virtual Reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3313831.3376243

[105] Run Yu and Doug A Bowman. 2020. Pseudo-haptic display of mass and mass distribution during object rotation in virtual reality. *IEEE transactions on visualization and computer graphics* 26, 5 (2020), 2094–2103.