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Going to the movies in VR: Virtual reality cinemas as alternatives to in-person co-viewing

Kata Szita [a,*], Wyatt Moss-Wellington [b], Xiaolin Sun [c], Eugene Ch'ng [d]

[a] ADAPT Centre of Excellence for AI-Driven Digital Content Technology, Trinity Long Room Hub Arts and Humanities Research Institute, Trinity College Dublin, College Green, Dublin 2, Ireland
[b] Department of Creative Arts & Communication, University of New England, Armidale, NSW 2351, Australia
[c] School of International Communications, University of Nottingham Ningbo China, 199 Taikang East Road Ningbo 315100, China
[d] NVIDIA Joint-Lab on Mixed Reality, School of International Communications, University of Nottingham Ningbo China, 199 Taikang East Road, Ningbo 315100, China

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ABSTRACT

Virtual reality cinemas offer computer-generated screening environments that resemble physical-world movie theaters for avatar-based viewers. Reflecting on virtual spectatorship in the context of social isolation, the present study investigates whether VR cinemas could provide an alternative for collective movie watching and whether they could facilitate an engaging experience similar to other, physical-world co-viewing environments. To measure these effects, we designed a behavioral experiment in which participants watched a feature film sequence either in VR or a physical screening room in the presence or absence of viewing companions. After viewing, participants' experiences—including emotional engagement, narrative empathy, presence, social experiences, and physical and mental well-being—were recorded using survey methods. We observed that VR viewing can produce an equally enjoyable film experience, as well as similar levels of emotional engagement and narrative empathy, while it leads to increased comprehension of characters' feelings and sense of narrative engagement. In addition, social viewing may mean less engagement and more distractions depending on the screening environment. We also found that even though previous virtual reality exposure negatively correlates with comfort and well-being during viewing, early adopters of technology and VR supporters are more likely to have an enjoyable and engaging film experience.

1. Introduction

Virtual reality offers a broad range of activities—including movie screenings that can appear as safe and convenient options for watching together when movement is limited, or when health-related concerns impinge upon social engagements. Given the lack of previous research into new co-viewing environments, the present study explores virtual reality cinematic experiences and investigates whether they could offer a sensation of community and engaged viewing.

The abundance of moving image screening devices now available allows for film spectatorship to take a variety of forms. Film-viewing can occur anywhere from designated screening rooms to open spaces, at predetermined times or spontaneously, with or without companions. While some of these viewing scenarios are rooted in the traditions of film spectatorship culture (Casetti, 2011) or promote strong engagements with a movie (Szita and Rooney, 2021) more than others, cinemas are still regarded among the most suitable venues for watching movies. Cinemas' inherent social framework, however, has been greatly challenged by restrictions following the Covid-19 pandemic. The same restrictions have at the same time hastened the popularization of remote interaction platforms, like virtual reality (Sykownik et al., 2021)—not least for film spectatorship.

Virtual reality (VR) cinemas offer computer-generated social viewing environments with avatar-based viewers, where a film is streamed from a central server or a user's personal computer and appears on a screen within the virtual space. These environments are designed to cover a broad collection of viewing setups, from virtual living rooms shared with friends to theaters for larger audiences (see Fig. 1). Virtual screening rooms may correspond to or emulate features of their physical counterparts. For instance, a home movie setup can include real-time interactions in the form of chat and voice messaging. Or, similar to physical-world cinemas, a virtual movie theater can house hundreds of

* Corresponding author.
E-mail address: szitak@tcd.ie (K. Szita).

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viewer-avatars simultaneously and offer premiere events or scheduled (ticketed) screenings.

Based on the growing popularity of virtual reality and the increasingly wide availability of equipment (Alsop, 2021), one may consider virtual cinemas as reasonable substitutes for public or private co-viewing environments, at home or at a physical cinema, in times when social engagements are limited. However, research has provided insufficient data to support or contradict notions of their experiential resemblances, or to characterize virtual cinematic experiences in general. The present study aims to fill this gap by introducing a methodological apparatus and empirically testing the extent to which virtual viewing experiences correspond with spectatorship in physical spaces. Based on its findings, we argue that VR cinemas can offer viewing experiences that induce a similar sense of community, narrative engagement, and emotional effect as physical-world screenings. In addition, these experiences can effectuate a high level of comfort regarding disease exposure. These findings contribute to scholarship and general knowledge of VR cinema as a novel form of entertainment and reflect on its potential for spectatorship and remote collective experiences that convey the sensation of watching together.

1.1. Collective viewing experiences

What we refer to as cinematic experiences—as opposed to pre-cinematic visual illusions and post-cinematic (digital) media experiences—are inherently collective. Cinemas are designed to house crowds of viewers simultaneously that view and engage emotionally with the same content, forming a dynamic system of individuals. Such a system includes individual interests, tastes, and, thus, responses, while it also functions in terms of social facilitation (see Strauss, 2002) or the "audience effect" (Hanich, 2014, 2018); that is, the tendency to perform tasks such as film-viewing in a specific manner to tailor one's behavior to the presence of others. In addition, feature films are often constructed in such a way that audience members' reactions exhibit significant synchrony in attentional directedness (Smith and Henderson, 2008; Smith and Mital, 2013) and even neural processes (Hasson et al., 2008).

Cinema's collectiveness is based on a shared space and stimulus, but it is a social, emotional, and cultural bond that frames collective experience and behavior: this is what provokes audience-wide laughter to a particular scene even if some would not find it funny otherwise (Hanich, 2018). Such a phenomenon can also be explained by what Zacks (2015) labels the "mirror rule" in audience behavior. This describes viewers' involuntary mimicry of reactions and body language of characters on the screen and the people surrounding them. However, as Zacks notes, learned social behavioral formulas keep excessive mirroring reactions in control, such as grimacing or waving back whenever an on-screen character waves.

Crucially, cinema-viewing is far from the only manner of co-viewing available, as successive technologies have proliferated means for social interaction over media, initially with televisions at home, the internet, digital streaming, and now wider availability of VR devices that can facilitate socializing and co-viewing over distances. Such changes in modes of viewing have diversified the environments where viewers engage with films, and the sense of community, narrative engagement, and emotional effect have become equally important as the environment itself. Empirical studies of cinematic and other co-viewing experiences demonstrate the effects of collective viewing and the presence of viewing companions on emotions and enjoyment. For instance, Harris et al. (2000) and Harris and Cook (2010) found that discomfort and attraction elicited by certain types of movie content varied with viewing companions, such as particular family members or partners. Harris and Cook (2010) located a negative correlation between enjoyment, screen content, and some shared viewing situations: for instance, unsurprisingly, that viewers report increased discomfort when watching explicit sexual content with their parents.

Others find that collective spectatorship generally produces more engaged viewing for a longer period of time, in contrast to watching films or television programs alone; and this is particularly true of home-based viewing (Mora et al., 2011; Yang et al., 2010). This, as Banjo et al. (2015) interpret it, implies a pleasure of shared viewing experiences. Correspondingly, regarding video game spectatorship (i.e., the phenomenon of watching others play in person or via live stream, see Taylor, 2018), previous research has established that viewers are motivated by social integration goals (Sjöblom and Hamari, 2017). In addition, social viewing activities positively affect a sense of both community and narrative engagement and provide stronger social ties than other mass media experiences (Hilvert-Bruce et al., 2018; Orme, 2021).

Just as social viewing generally involves audience members' impact on one another, it may imply distractions too: one can be distracted by others' talking or whispering, squirming, munching, or looking at their phones. When comparing narrative persuasion and transportation related to viewing fantastical films in high and low distraction conditions, Zwarun and Hall (2012) concluded that distractions arising from the surrounding space and its inhabitants negatively impact comprehension and narrative transportation. While not particularly studying social viewing, Szita and Rooney (2024) arrived at similar conclusions when measuring the role of distractions in viewing fiction films on screens of different types. They found that screen sizes and, therefore, immersive quality as well as the quality of external (non-filmic) sound or visual effects have an impact on the chances of being distracted. Distractions that are related to the particular narrative are less likely to

Fig. 1. A virtual reality cinema in Bigscreen VR. Image source: https://www.facebook.com/bigscreenvr.

affect engagement with the movie or impair one's attention than those that are unrelated (e.g., a phone ringing during a nature documentary). This suggests that fellow viewers' reactions to a movie may not be distracting if they are linked to the stimulus: in scenarios that are presented by Hanich (2014, 2018) and Zacks (2015), others' laughter at a funny scene or ducking when a large object is flying toward the camera will not likely become distractions, rather, they may reinforce viewers' reactions.

1.2. Virtual social interactions and spectatorship

Remote forms of participation in internet-based social networks have been widely investigated for their effects on social engagement (Hassouneh and Brengman, 2014; Zhou et al., 2011). Some have reported changes to these engagements during times of isolation, including research that suggests digital media platforms, such as social media, could ease anxiety related to lockdowns at the beginning (Bendau et al., 2021; Wiederhold, 2020) and in the later stages (Thygesen et al., 2022) of the Covid-19 pandemic.

Given opportunities for VR use during the pandemic, other studies found that social virtual reality (three-dimensional immersive environments for social activities, such as AltspaceVR or Rec Room, see Dzardanova et al., 2018) can offer spaces for socialization activities with psychological benefits, including when social distancing or isolation measures are in effect (Barreda-Ángeles and Hartmann, 2022). Barreda-Ángeles and Hartmann (2022) concluded that spatial and social presence in a virtual environment increases the feelings of relationality and enjoyment that are generally associated with socialization activities. When completing playful activities with friends in VR, users can feel present in a virtual space and consider other users' avatars as social companions. This eases anxiety and presents a suitable alternative for activities when mobility is limited.

Social virtual reality spaces are used for various activities, including connecting to loved ones (Maloney and Freeman, 2020; Zamanifard and Freeman, 2019) and meeting new people (Latoschik et al., 2019). Further, they may also be functional in attempts to hide one's real-life social identity toward the goal of assimilation into social groups (Maloney and Freeman, 2020; Szita, 2022). A recent study of virtual reality and users' motivations found that respondents value social VR platforms' capacity to satisfy social needs and offer platforms for entertainment and activities that promote personal growth (Sykownik et al., 2021). The authors also concluded that social VR's popularity lies in the immersive quality that exceeds other digital social platforms like social media or game sites.

Desires for social engagement may be motivations for immersing in free-time activities, such as reading or watching television series (Derrick et al., 2009; Mar et al., 2011). In social virtual reality spaces, the most typical activities are related to socializing, learning, and entertainment (Sykownik et al., 2021). Using an online survey, Sykownik et al. (2021) found that entertainment is generally linked to collective activities and involves gameplay, music and dance, and film or video viewing.

Studies of film or video viewing experiences in virtual reality commonly focus on cinematic virtual reality, a setting where audiovisual (narrative) content is presented in 360° and viewed using a head-mounted or portable device that engages motion tracking (MacQuarrie and Steed, 2017).[1] That is, the moving-image content surrounds the viewer, and the momentary visual and sonic field (i.e., what a viewer can see and hear) depends on the body or head position. The corpus of these studies provides design and storytelling principles (Dooley, 2017; Rothe and Hußmann, 2018), evaluation methods (Bala et al., 2017; Reyes, 2018), as well as conclusions regarding viewing experiences. For instance, Syrett et al. (2016) explored patterns of comprehension and engagement with a short feature film watched using an Oculus Rift VR headset.

In a comparative study, Van Damme et al. (2019) measured the sense of presence and fidelity across viewers using an Oculus Rift, a cardboard viewer, or YouTube either with a fixed or adjustable viewpoint. They found that the more immersive the condition was (head-mounted display and cardboard viewer), the more viewers engaged with the content. Similarly, Fonseca and Kraus (2016) compared viewing experiences in VR and on a tablet and concluded that VR watching elicits higher levels of emotional engagement. Studying information acquisition, comprehension, and recollection, Szita et al. (2021) contrasted cinematic VR viewing with stationary screen viewing. They confirmed that VR viewing leads to a higher sense of presence and emotional engagement with a narrative, but the 360-° field of view impairs the accuracy of information acquisition. Other studies also note the drawbacks of 360-° film and video viewing, including a lack of framing and unambiguous attention control that negatively impact both comprehension (Van den Broeck et al., 2017) and overall viewing experiences (Dorta et al., 2016).

Shared virtual reality cinematic environments exclude the issues of 360-° viewing based on their immersivity, remote access, and screen-based setup. However, there are limited conclusions regarding VR cinemas. One exception is a study by Shafer et al. (2018) that compared an early VR simulation of cinemas, the then-discontinued Riftmax Theater, to physical cinema viewing. Shafer et al. found no differences between viewing scenarios in terms of engagement with a movie and concluded that movie viewing can be equally pleasant in VR—even though the used VR software was far less realistic than its newer counterparts. In that study, the authors did not control for social and individual viewing scenarios (cinema was always social and VR was always individual).

1.3. The present study

Based on a changing digital media landscape and new viewing practices, this paper presents an initial investigation into whether VR cinemas could provide an alternative for collective movie watching. While many aspects of social VR platforms—chiefly, immersive remote participation—have been highlighted in previous research as means to advance social engagements during isolation, little attention has been paid to the specific case of movie watching. Given the popularity of film, video, and television within the framework of entertainment, and the impact of collective spectatorship on emotional engagements and formation of social ties, this case also predicts significant conclusions regarding virtual social behavior. Studying experiences afforded by new forms of collective spectatorship can initiate further research into collective behaviors such as spontaneously forming (potentially anonymous) crowds in virtual spheres, and interface design for virtual social environments.

Previous research described above has also addressed qualities of social VR platforms that provide a sense of bodily proximity when sharing virtual spaces, for instance, with partners or close family members (e.g., Freeman and Acena, 2021). At the same time, avatar design options may be used to mask real-life social identities and to approximate or distance oneself from other users depending on users' situational and social needs (e.g., Maloney and Freeman, 2020). Yet, there are no clear conclusions on users' attitudes toward the proximity of others' avatars when it comes to health and physical and mental well-being. Thus, we also aim to provide an understanding of how users feel about the closeness of others in virtual spheres—both viewing companions represented by an avatar and digital non-player characters (NPCs)—when social distancing measures are in effect in their physical lives.

To explore the effects of virtual cinemas on viewing and social

[1] The expressions "VR cinema" and "virtual reality cinema" appear broadly in previous research (see, for example, Kang, 2017; Pillai & Verma, 2019), but they denote what is labeled as cinematic virtual reality above (for a definition of cinematic virtual reality, see MacQuarrie & Steed, 2017).

experiences in the context of social isolation, and to understand which populations may benefit most from VR cinemas, we designed a behavioral experiment in which participants watched a feature film sequence either in a virtual cinema or a physical screening room in the presence or absence of viewing companions. We modeled highly popular viewing scenarios: watching a movie using a VR cinema application in the presence of other avatars (in our case, they were NPCs) and watching in a physical space in a small group—akin to home cinema or similar experiences—but we also controlled the effect of co-presence by including individual viewing setups both for VR and screen viewing. Participants' engagement with the movie, social experience, health-related sensations, and their attitudes toward VR technology and social activities were recorded using survey methods. Applying this design, the study aimed to answer the following research questions:

RQ1a: How do VR viewing and the presence or absence of viewing companions affect film experiences?
RQ1b: How do VR viewing and the presence or absence of viewing companions affect viewing experiences and the sense of comfort and well-being during collective viewing?

Based on previous research highlighted above, we hypothesize that due to the immersive qualities of social virtual reality spaces and the presence of avatar-users, VR cinemas can elicit a strong sense of social presence, facilitate an engaging film experience, and provide a safe and comfortable environment without an assumed disease exposure related to the aftermath of the Covid-19 pandemic.

RQ2a: How do media use habits impact viewers' experiences and sense of comfort and well-being in virtual cinemas?
RQ2b: How do personality traits linked to social behavior and technology-related attitudes impact viewers' experiences and sense of comfort and well-being in virtual cinemas?

We foresee a positive effect of personality traits related to openness to new experiences and technologies on engaging with films in virtual reality cinemas. Moreover, users with social personality types, in general, are also expected to feel comfortable among virtual companions and have a sense of collective experience.

2. Method

2.1. Design

To isolate the effects of viewing circumstances, the experiment followed a two-by-two factorial design. In this design, viewing environments (virtual reality and screen viewing) and the presence or absence of viewing companions were the independent variables. The combination of these factors delivered four viewing conditions: virtual reality viewing with and without fellow viewers (VR social and VR individual) and screen viewing with and without fellow viewers (screen social and screen individual). The VR conditions emulated a cinema space, while the screen conditions emulated private or local co-viewing with physically present companions, using lighting, resolution, and viewing conditions equivalent to a home theater. In order to maintain the comparability of viewing conditions, but avoid biases due to the repeated viewing of the same stimulus, two movie sequences were used—one for all the VR conditions and the other for all the screen conditions. Participants viewed both sequences in each viewing environment with and without companions. Thus, each participant was tested in the VR social and screen individual or the VR individual and screen social conditions, where the order of conditions was counterbalanced to produce an approximately equal number of trials for each combination. Such an experiment setup (that participants were assigned for two of the four conditions) required an incomplete mixed design. This allowed us to utilize the contributions of a between-groups and within-subjects design, avoiding the biases of repeated viewing while measuring participants as their own control group that holds economic benefits.

2.2. Stimuli

The two movie sequences were derived from the feature film, *The Walk* (Zemeckis, 2015). They were used in previous empirical research following incomplete design to study viewing experiences under different circumstances (Szita and Rooney, 2021). In that study, the authors argue for the two sequences' comparability based on their congruent narrative content, emotional affect, visual language (salience, camera movement), and structure (shot length).

The Walk depicts the wire-walking act of French artist Philippe Petit between the twin towers of the World Trade Center in 1974. The clips used in the experiment were approximately nine-minute sequences of the main protagonist's multiple walks. In each sequence, Petit is depicted on the wire completing a single walk (he is on the wire, then successfully disembarks onto one of the towers). In both, he is shown in the company of others in outdoor and indoor spaces in daylight and darkness, and other characters, such as his accomplices, passers-by, and policemen, appear on the towers and the neighboring streets. Each sequence includes a structure of exposition (Petit's self-narrated contemplation of his act and its expected success), rising emotional tension (Petit on the wire, fear for his life), and climax (the completion of his act and characters celebrating). Therefore, each is regarded as a self-standing narrative unit with individual storylines. This means that while the sequences carry indications for the order of the walks in the whole movie's context, the narrative units of the two clips allow for their order to be reversed and their content to be treated as distinctive narratives.

Additional considerations when choosing the film sequences included their relatively apolitical content, which eliminated potential ideological biases in evaluative survey responses, and ease of comprehension of the emotional stakes of each sequence without background knowledge or narrative context. These were important considerations, too, for data collection involving chiefly Chinese and non-native English speaker participants.

2.3. Participants

Seventy-three volunteers (40 females, 32, males, 1 not stated) aged 18–32 (M = 23.23, SD = 3.49) participated in the experiment. Recruitment followed convenience sampling and the majority of participants were university students and staff members. Each participant was tested twice, and this produced a sample of 146 trials. The criterion for taking part was sufficient visual and hearing abilities, knowledge of English, and having the bodily capacities to wear and use a head-mounted display. Participation was conditional to providing written informed consent in accordance with the protocols approved by the Research Ethics Panel of the University of Nottingham Ningbo China. Based on university policies, participants received no compensation.

Participants answered questions regarding their media use habits. Generally, they watch movies and television programs on computers (83.7 % of respondents), in cinema (63.8 %), on mobile phones or tablets (61.7 %), and on TV (36.2 %). No participant claimed to watch movies or television series using VR. Over half of the participants (51.1 %) were VR novices, who had never used head-mounted virtual reality equipment prior to the experiment.

2.4. Conditions and setup

The four viewing conditions were designed to measure the effects of digitally created and natural environments (VR vs. screen viewing) as well as the presence or absence of viewing companions (individual vs. social viewing). Deducting insufficient data or missed trials, 143 trials

provided valid data. This produced 38 trials in the VR individual, 35 in the VR social, 34 in the screen individual, and 36 in the screen social condition. However, due to technical errors, analyses were completed on 141 trials. From this, two more trials were excluded for analysis of previous VR experience and VR using habits due to contradictory survey responses.

In the virtual reality conditions, the movie sequence (image and sound) was presented in a virtual movie theater by Bigscreen VR accessed using head-mounted displays (see Fig. 2). For this experiment, we created a private screening that was not available for anyone outside of the experiment team. The movie sequence was directly streamed from a hard drive using a lab PC. In Bigscreen VR, we used the "Retro cinema" room, which resembles a regular theatrical screening room with multiple rows of seats and a screen covering the front-end wall of the room. The room was also chosen as it enabled manual control of the presence of virtual companions that created a simulated social scenario comparable to in-person viewing. These are non-player characters—digitally created (non-photorealistic) avatars that are present in the screening room but are not linked to users or developers. While their number and placement are automatic, we found that in "Retro cinema" NPCs are fairly close to the participant's viewpoint to present a manner of social sensation without making the room crowded. NPCs were present in the VR social condition, but this function was disabled in the VR individual condition, where the participant was the only avatar present. The NPCs appeared as quiet and motionless, yet potentially interactive agents, thus the VR social condition offered a simulated social experience while co-viewing in the screen social condition was unsimulated. Participants were unaware that the other avatars were not linked to human users. This was to ensure that they perceive them as any viewing companions so that our simulated and unsimulated social conditions were comparable.

The movie sequence in both VR conditions was presented on the screen with approximately 45° of horizontal viewing angle relative to participants. In regular cinemas, this is the viewing angle of those sitting on the prime seats (the ones sold the fastest) around the back two-thirds of an auditorium (Allen, 1999). To achieve this angle, the participant's avatar was placed in the middle of the fifth row of the room.

In the screen conditions, we used a 70-inch screen (178 cm diagonal) and seated participants approximately two meters away to achieve the same viewing angle as in the VR cinema (see Fig. 3). Further ensuring comparability, during trials, lights were dimmed to create a similarly dark atmosphere as in the VR cinema space. Sound was presented through the screen's inbuilt speakers, so the stereo (but not surround) sound corresponded to that of the VR conditions. Similar to the VR conditions, the two screen conditions differed in the number of viewers: in the screen individual condition, participants watched the sequence one at a time; in the screen social condition, a group of five participants watched together. In the latter case, participants were seated such that their viewing angles were similar (between approximately 42–47°).

Fig. 2. Virtual reality viewing setup. Screenshot by the authors.

Fig. 3. Screen viewing setup (photo taken between trials).

2.5. Procedure

Data collection took place on campus at the University of Nottingham Ningbo China during the summer of 2021 while complying with the Covid-19 safety regulations of the time. Before data collection, participants were assigned time slots for each of the viewing conditions. Generally, the same participant was measured at two different times (e.g., morning and afternoon of the same day). This was necessary for technical reasons—for the research team to have enough time to disinfect and prepare the equipment between sessions—but it also provided the opportunity for a long enough break for each participant so that the repeated measures would less likely bias the results.

Before each experiment session, participants received an oral briefing, including information on safety and the procedure, and signed the informed consent form. Following the briefing, participants were seated in front of the screen or the VR headset was applied and calibrated individually (interpupillary distance, viewing direction, etc.).

When the screening equipment was set up, participants watched the assigned movie sequence. After each viewing session, they were asked to complete a questionnaire about their demographics and media use habits, attitudes toward VR, personality traits, and evaluation of viewing experience (see below). Including briefing, preparations, viewing, and completing the questionnaire, one experiment session took no more than 30 min.

2.6. Measures

During this experiment, participants' reactions were measured using a questionnaire. The questionnaire consisted of two main parts, a general questionnaire and an experience questionnaire. The general questionnaire included items on demographics (e.g., gender and year of birth) and media use habits (e.g., frequency of watching movies and television series on certain devices and experience with VR). The next section of the general questionnaire was devoted to personality traits based on extroversion, openness to experience, and technology acceptance (Smith et al., 2021). This included statements, such as "I am glad if things are happening around me," "I am fascinated by themes I find in nature and art," and "I generally adopt new technologies before

everybody else." Participants rated their agreement/disagreement with the statements on seven-point Likert scales ranging from *not at all* to *completely*. The last section of the general questionnaire focused on attitudes toward virtual reality and technology adoption. The section was assembled by the authors based on research question 2 and included statements such as "Virtual cinematic experience is important in the current climate," and "Virtual cinematic experience that incorporates groups of co-viewers is important." Similar to the preceding section, seven-point Likert scales were used ranging from *not important at all* to *extremely important*.

The experiment questionnaire was assembled to measure engagement with the movie sequence and its narrative, empathy toward characters, presence, as well as specific factors regarding the viewing circumstances. It included statements that participants rated on seven-point Likert scales ranging from *not at all* to *completely*. Items assessing presence were based on Fonseca and Kraus (2016), Qin et al. (2009), Szita and Rooney (2021), and Witmer and Singer (1998) and included statements, such as "I felt that I was present in the fictional world of the movie" and "I become less aware of the real world and my personal problems while watching the movie." Correspondingly, we used statements that measure the specific elements of cognitive and affective empathy, compassion/sympathy, and character allegiance, for instance, "I wanted the main character to succeed in his challenge."

In terms of the specific viewing circumstances, items were based on previous research regarding place and plausibility illusion (Slater, 2009; Usoh et al., 2000; Witmer and Singer, 1998). They included statements, for example, "I had a sense that others were present in the same place" and "The environment felt natural." Additionally, a set of items focused on health, well-being, and concerns around the current health-related climate. These included statements like "I felt dizzy while watching the movie," "I felt safe in the environment where I watched the movie," and "I felt it would have been appropriate that viewers wear masks."

3. Results

In the following, we report the results of tests for comparing viewer experiences in the different viewing conditions and the correlations between experiences and the responses given to the general questionnaire (media use habits and personality traits). These aim to reveal the relations between and distinctiveness of VR and screen viewing, social and individual viewing, as well as media-related attitudes and personality, and how each variable affects viewers' responses.

3.1. Viewing conditions

To compare responses between viewing conditions, we used one-way ANOVA, treating participants in each viewing condition as members of separate groups (see our rationale on comparability above). We ran the analysis for the dependent variables the experiment questionnaire provided. Mean values for each viewing condition are displayed in Table 1.

3.1.1. Film experience

Based on RQ1a, we analyzed questionnaire items for viewers' film experiences that included scales measuring emotional effects, narrative presence, and narrative empathy. For each scale, we ran reliability tests that all determined adequate consistency between the items (Cronbach's alpha values are reported below). Then, we tested homogeneity: the results of the Levene's test determined whether the conclusions below are based on the analysis of variance or a robust test of equality of means (Welch's test). For post hoc tests to evaluate pairwise differences between groups, Tukey's test was used.

3.1.1.1. Emotional effects. The scale contained two items to measure enjoyment and the narrative's emotional effects ($\alpha = 0.931$). Responses showed no significant differences between viewing conditions (F (3, 137) = 2.628, $p = 0.053$).

3.1.1.2. Narrative presence. We measured viewers' sensation of presence in the fictional narrative using four questionnaire items ($\alpha = 0.86$) and found significant differences between viewing conditions (F (3, 137) = 11.52, $p < 0.001$). The pairwise comparison revealed that each VR condition had significantly higher values of narrative presence than the screen conditions.

3.1.1.3. . Narrative empathy. Four items were used to measure the different elements of narrative empathy ($\alpha = 0.886$). The one-way ANOVA showed significant differences (F (3, 137) = 2.672, $p = 0.05$), however, the pairwise comparisons revealed no difference. When analyzing the individual questionnaire items, we found that the only item with significant difference was participants' understanding of the main character's feelings (Welch's test (F (3, 75.276) = 3.755, $p = 0.014$) that showed higher ratings for the VR individual condition than the screen social condition.

3.1.2. Viewing experiences, comfort, and well-being

To provide answers for RQ2b, we ran the same tests for the indices of viewing experiences, comfort, and well-being.

3.1.2.1. Physical presence in the viewing space. The physical presence scale included three items with a reliability of $\alpha = 0.854$. Significant differences were found (F (3, 137) = 6.462, $p < 0.001$). Participants felt more present in the VR screening environment than in the physical screening room: the VR individual condition showed significantly higher values than the screen individual condition and the VR social condition showed significantly higher values than each of the screen conditions.

3.1.2.2. Social experience. In terms of having a social experience, we found significant differences between viewing conditions—again in favor of VR viewing—after comparing participants' ratings on six items ($\alpha = 0.81$): F (3, 137) = 8.766, $p < 0.001$. The VR social condition showed higher values than each of the screen conditions. In addition, unsurprisingly, the VR social condition was rated more social than the VR individual condition.

3.1.2.3. Distractions. We measured participants' sense of being distracted by the environment or viewing companions using three items with a Cronbach's alpha of 0.709. The ANOVA detected significant differences (F (3, 137) = 3.048, $p = 0.031$) and we found that participants were more distracted in the VR social condition than the VR individual condition, but no differences were found for the screen conditions.

3.1.2.4. VR health effects. We measured participants' sensation of dizziness and disorientation (which are typical symptoms of using virtual reality headsets) by two items ($\alpha = 0.807$). No significant differences were found: (F (3, 137) = 1.667, $p = 0.177$).

3.1.2.5. Covid-19-related attitudes. We measured how people react to social experiences after experiencing lockdowns and social distancing measures, as virtual reality experiences were highly praised as alternatives for physical-world social experiences. In the lack of reliable scales, we measured participants' Covid-19-related attitudes with four specific questionnaire items.

While ratings of feeling safe during watching did not show significant differences (F (3, 137) = 0.988, $p = 0.4$), loneliness (F (3, 74.756) = 3.847, $p = 0.013$) was rated significantly higher in the screen individual than in the screen social condition.

Responses to the items measuring people's attitudes based on the general health-related climate during the Covid-19 pandemic were not significantly different between viewing conditions. These included

Table 1
ANOVA: Mean values, significant differences, and effect sizes for the four conditions.

Item	Significant difference	VR individual		VR social		Screen individual		Screen social		Effect size
		M	SD	M	SD	M	SD	M	SD	
Film experience										
Emotional effect		4.763	1.515	4.721	1.304	4.015	1.422	4.167	1.304	0.054
Narrative presence	VR ind–screen ind VR ind–screen soc VR soc–screen ind VR soc–screen soc	4.638	1.196	4.493	1.034	3.439	1.201	3.465	1.086	0.201
Narrative empathy		5.204	1.226	5.103	0.894	4.583	1.302	4.632	1.173	0.055
Viewing experience, comfort, and well-being										
Physical presence	VR ind–screen ind VR soc–screen ind VR soc–screen soc	4.588	1.05	4.725	1.02	3.677	1.3	3.944	1.266	0.124
Social experience	VR ind–VR soc VR soc–screen ind VR soc–screen soc	3.395	0.879	4.353	1.027	3.091	1.148	3.491	1.191	0.161
Distraction	VR ind–VR soc	2.667	1.096	3.353	1.044	3.273	1.156	3	0.969	0.063
Dizziness		2.316	1.087	2.853	1.276	2.439	1.095	2.333	1.128	0.035
Feeling safe		5.132	1.711	5.118	1.472	5.424	1.226	5.639	1.552	0.021
Feeling lonely	screen ind–screen soc	2.395	1.748	2.794	1.684	3.182	1.928	1.917	1.36	0.073
Disease exposure		2.132	1.563	2.265	1.543	2.364	1.711	1.778	1.017	0.023
Mask wearing preference		3.421	1.825	3.382	1.724	2.788	1.616	2.917	1.763	0.026

responses to "I felt I was exposed to infectious diseases" (F (3, 73.428) = 1.445, $p = 0.237$) and "I felt it would have been appropriate that viewers wear masks" (F (3, 137) = 1.202, $p = 0.312$).

3.2. The effects of media use habits and personality traits

To analyze how personality and media-related attitudes affect viewing experiences (RQ2), we ran ordinal logistic regression analyses (Osborne, 2015). By these, we aimed to reveal whether users of various screening platforms with certain traits of extroversion, openness to experience, and technology acceptance would engage with a virtual reality screening differently than others. We extended these analyses for trials from the two VR conditions and the independent and dependent variables were responses to the general and experience questionnaires, respectively.

3.2.1. Media use

As per RQ2a, the ordinal logistic regression analysis investigated the relationships between VR participants' responses and their media use habits. While cinemagoing,[2] previous experience with virtual reality, and general VR use did not predict viewing experiences, significant regression equations were found between the frequency of cinemagoing and being distracted while watching ($Wald\ \chi^2 = 3.953$, $p = 0.047$). Thus, at 95% confidence interval (1.007, 2.738), the effect on distraction was 0.507 ($SE = 0.255$). Presence-related variables in the viewing environment, including feeling a strong presence ($B = -0.447$, $SE = 0.247$, $Wald\ \chi^2 = 3.276$, $p = 0.07$) and encountering a natural experience ($B = 0.42$, $SE = 0.252$, $Wald\ \chi^2 = 2.77$, $p = 0.096$) in a natural environment ($B = -0.282$, $SE = 0.242$, $Wald\ \chi^2 = 1.357$, $p = 0.244$) showed no significant effects with the frequency of cinemagoing.

The analysis was completed even for the independent variable of cinemagoing in general (that is, whether or not one watches movies or television series in cinema). Significant negative correlations were found in terms of narrative empathy (understanding what the character was feeling; $B = -1.024$, $SE = 0.495$, $Wald\ \chi^2 = 4.277$, $p = 0.039$), presence in viewing environment (the environment being sensed as natural; $B = -1.034$, $SE = 0.489$, $Wald\ \chi^2 = 4.475$, $p = 0.034$), and health-related attitudes (wearing masks being desired; $B = -1.146$, $SE = 0.53$, $Wald\ \chi^2 = 4.679$, $p = 0.031$). Thus, those who claimed to not go to the cinema were more likely to report a strong sense of narrative empathy and presence in the viewing environment, and higher desire for people to wear masks.

Some effects of VR use were also detected. Participants who had used VR before were more likely to report dizziness while watching the movie in VR with an effect of 1.407 ($SE = 0.59$, $Wald\ \chi^2 = 5.697$, $p = 0.017$). Yet, no significant results were detected for the other variables related directly to physical health or feeling disoriented ($B = 0.192$, $SE = 0.552$, $Wald\ \chi^2 = 0.121$, $p = 0.728$).

Those who used VR more often were less likely to feel safe in the virtual environment of the experiment ($B = -0.895$, $SE = 0.411$, $Wald\ \chi^2 = 4.75$, $p = 0.029$). Not feeling safe, however, is seemingly not tied to the effects of the pandemic, as no significant effects were shown between the frequency of VR use and the feeling of being exposed to infectious diseases ($B = 0.265$, $SE = 0.352$, $Wald\ \chi^2 = 0.567$, $p = 0.451$).

No effects were detected for the specific case of movie watching in VR (whether participants choose VR for watching movies or television series), as no participants claimed to use VR for spectatorship outside of the study.

3.2.2. Personality traits

To answer RQ2b, we ran the ordinal logistic regression analyses for personality traits, technology adoption, and attitudes toward virtual reality as independent variables. The significant regression equations are reported below.

3.2.2.1. Extroversion and openness to experience. Significant regression equations were detected between the variables of extroversion and openness to experience and engagement with the movie. The story's emotional effect showed a positive correlation with VR participants' interest in nature and art ($B = 0.353$, $SE = 0.174$, $Wald\ \chi^2 = 4.106$, $p = 0.043$).

Regressions were significant in terms of narrative empathy as well, but we found contrasting results. While the variables "I felt what the characters were feeling" and "I wanted the main character to succeed in his challenge" showed positive correlations ($B = 0.58$, $SE = 0.189$, $Wald\ \chi^2 = 9.472$, $p = 0.002$ and $B = 0.595$, $SE = 0.243$, $Wald\ \chi^2 = 5.989$, $p = 0.014$), participant's understanding of the main character's feelings showed both negative and positive correlations with the independent variables of extroversion. In the reported enjoyment of situations involving a lot of people, the correlations were positive ($B = 0.605$, $SE = 0.192$, $Wald\ \chi^2 = 9.917$, $p = 0.002$), meaning that participants with higher extroversion ratings would claim that they understood the main

[2] Participants rated the frequency of cinemagoing in times not affected by social distancing and lockdown measures.

character's feelings better. However, when reporting being glad if things happen around them, this correlation was reversed ($B = -0.576$, $SE = 0.261$, $Wald\ \chi^2 = 4.857$, $p = 0.028$).

Regarding presence in the viewing environment, the following variables showed significant regression: strong sense of presence in the viewing space ($B = 0.469$, $SE = 0.226$, $Wald\ \chi^2 = 4.3$, $p = 0.038$) and the viewing experience being natural ($B = 0.334$, $SE = 0.17$, $Wald\ \chi^2 = 3.858$, $p = 0.0495$). Both of these variables correlated positively with extroversion and openness showing that people with higher extroversion have a stronger sense of spatial presence and acceptance of the virtual environment.

Our results show that participants' ratings of the statement "I am glad if things are happening around me" during viewing correlated with their sense of being a part of a group when watching with virtual viewers ($B = 0.436$, $SE = 0.221$, $Wald\ \chi^2 = 3.906$, $p = 0.048$).

Well-being showed a significant relationship to extroversion too. Feeling lonely correlated positively ($B = 0.372$, $SE = 0.185$, $Wald\ \chi^2 = 4.033$, $p = 0.045$), and thinking that masks should have been worn by (virtual) companions negatively ($B = -0.376$, $SE = 0.178$, $Wald\ \chi^2 = 4.455$, $p = 0.035$) with extroversion.

3.2.2.2. Technology acceptance. We found significant regression equations between the independent variables of technology and virtual reality acceptance and viewing experiences. Participants claiming to be fascinated by technology and who would advocate for VR cinematic experiences were more likely to rate their enjoyment of the movie higher. For the former, this effect was 0.478 ($SE = 0.182$, $Wald\ \chi^2 = 6.935$, $p = 0.008$), and the latter, it was 0.56 ($SE = 0.236$, $Wald\ \chi^2 = 5.643$, $p = 0.018$). Those with higher-rated fascination with technology in general experienced higher narrative empathy: wanting the best for characters ($B = 0.441$, $SE = 0.17$, $Wald\ \chi^2 = 6.735$, $p = 0.009$) and wanting the main character to succeed ($B = 0.71$, $SE = 0.186$, $Wald\ \chi^2 = 14.523$, $p < 0.001$). VR cinema advocates were also more likely to sense that time flies quickly while watching the movie in a virtual environment ($B = 0.516$, $SE = 0.225$, $Wald\ \chi^2 = 5.265$, $p = 0.022$).

Results showed significant regressions even for presence in the virtual viewing environment, social experiences, and health. Those fascinated with technology rated their sense of the environment being natural higher ($B = 0.348$, $SE = 0.169$, $Wald\ \chi^2 = 4.234$, $p = 0.04$), and so did VR cinema advocates ($B = 0.614$, $SE = 0.228$, $Wald\ \chi^2 = 7.227$, $p = 0.007$). VR cinema advocates also felt a stronger sense of presence in the virtual viewing environment ($B = 0.511$, $SE = 0.2286$, $Wald\ \chi^2 = 4.999$, $p = 0.025$).

In terms of assuming the same manners as in a real cinema, VR viewers' ratings for VR cinemas being important were positively correlated: those advocating for VR cinematic experiences rated this item higher ($B = 0.485$, $SE = 0.223$, $Wald\ \chi^2 = 4.758$, $p = 0.029$). They were also more prone to encounter a social experience while watching ($B = 0.621$, $SE = 0.227$, $Wald\ \chi^2 = 7.513$, $p = 0.006$).

Participants rating their fascination with technology higher were more likely to feel the need to interact with other viewers ($B = 0.406$, $SE = 0.17$, $Wald\ \chi^2 = 5.742$, $p = 0.017$). In addition, those who adopt new technologies more quickly claimed to be less disoriented while watching in VR ($B = -0.31$, $SE = 0.156$, $Wald\ \chi^2 = 3.945$, $p = 0.047$).

4. Discussion

The present study measured the impacts of virtual reality cinema on viewing and social experiences, as well as the factors of media use habits and personality traits on the likeliness for engaging positively with VR spectatorship. Reflecting on the research questions, the results show that viewing circumstances have some effects on narrative empathy and presence, as well as physical presence in the viewing environment, social experiences, and well-being. We also found that media consumption habits impact emotional engagement and narrative empathy, as well as physical presence, social experiences, and well-being-related attitudes. Personality traits correlated with responses to all clusters of variables measuring engagement, comfort, and well-being.

Supporting the notion that virtual cinema can serve as an alternative to physical-world collective viewing, we found that viewing conditions do not impact the general impression (i.e., enjoyment) of a movie or its emotional effects, which corresponds to previous research (Shafer et al., 2018). In addition, no significant differences were detected between viewing conditions regarding narrative empathy (empathizing with characters or understanding how they feel). No differences appeared for the variables measuring health (dizziness and disorientation) and well-being (feeling safe or exposed to infectious diseases and mask-wearing preferences) either. In terms of being distracted, no differences appeared between screen and VR viewing, however, social viewing produced higher distraction than individual viewing in VR. This suggests that even though the viewing companions were non-player characters, participants treated them as potential fellow viewers and sources of distractions.

For the variables where significant differences were detected between viewing conditions, we observed that VR viewing produced higher evaluative ratings than screen viewing in all cases: participants reported higher presence in the narrative and the fictional world, stronger sensation of presence in the viewing environment, and a stronger sense of being involved in a social experience. This largely corresponds to previous research that shows that virtual reality viewing experiences are generally more immersive than screen viewing (Szita et al., 2021; Van Damme et al., 2019), VR users are less susceptible to distractions (Fonseca and Kraus, 2016), and social VR settings promote highly social experiences (Barreda-Ángeles and Hartmann, 2022). However, feeling more present in the VR viewing environment than in the physical one is a remarkable result. This may be explained by participants who had tried VR before comparing the environment's naturalness to previous VR experiences or other virtual environments, although we could not confirm this—no significant correlations were found between the presence variable and VR use (previous experience and frequency of use). A corresponding explanation may relate to imprinting or the "baby duck syndrome," the learning of characteristics of specific types of information: human–computer interaction research applies this concept for the case when users acquaint themselves with a new system and judge subsequent systems based on the first one. This means that users would prefer systems or stimuli that are familiar or similar to their first encounters (Seebach, 2005). Accordingly, users with previous VR experiences would apply their VR-related "imprints" instead of comparing the experience with physical-world ones. These findings may also be linked to the experiment setup: while the VR condition involved a virtual cinema that resembled a movie theater, the screen condition was based on viewing in a laboratory (university) setting, more similar to a home movie experience than a physical cinema space. This point needs further investigation to rule out methodological shortcomings.

The second set of research questions focused on correlations between virtual cinematic experiences and media use, personality traits, and technology-related attitudes, respectively. Results showed that those who have used virtual reality headsets before are more likely to experience dizziness and less likely to feel safe in the virtual environment. This contradicts the assumption that VR experiences ought to become more pleasant and natural over time (Sagnier et al., 2020). Although these findings are controversial, we found no other effects of previous VR use. This can probably be explained by the fact that the majority of the participants were new to head-mounted virtual reality technology and none of them watched movies in VR in general.

The use of other types of screening platforms showed broader correlations with viewing experiences. For instance, cinemagoers experienced less narrative empathy during the experiment. They were also more likely to be distracted while watching a movie and feel less present in the physical viewing environment (feeling that the environment was

unnatural), which may be attributed to the unfamiliarity of virtual cinema rooms or their strangeness compared to real-world theaters. Virtual cinematic experiences had limited effects on those who watched movies on televisions, computers, and mobile devices: some positive correlations were detected in terms of emotional engagement and narrative empathy, as well as social experience and physical presence. This speaks to the different affordances between environments that are intrinsically co-viewing spaces (e.g., cinemas) or that can be tailored to social or individual experiences (private spaces, individual screens, and the home); audiences are primed with existing media use preferences correspondent to personality traits and their expression.

Comparing responses to the items that measure attitudes toward technology and VR to those that record film viewing experiences, we found positive effects of technology acceptance. Fascination by technology predicted higher enjoyment of the movie, empathy with characters, as well as acceptance of the environment as being natural. Similarly, early technology adoption led to a decrease in feeling dizzy/disoriented. In regard to the specific case of VR cinemas, those who rated the importance of virtual cinemas higher were more likely to enjoy the movie, experience narrative and physical presence in the fictional and virtual environments, and feel the benefits of collective viewing. These findings correspond with those of Sagnier et al. (2020) who demonstrated that technology acceptance and the intention to use VR increases its perceived usefulness as well as the comfort and ease of use.

In terms of health and well-being, correlations were found for computer users (for watching movies) who were more likely to feel lonely than others and mobile users who were less likely to feel safe in the virtual environment. Those who watched movies mostly in cinemas in non-pandemic times were less likely to feel that viewers should wear masks in the virtual screening room. Regarding mask-wearing, people that are more open-minded (who are fascinated by themes in nature and arts; see Smith et al., 2021) were also less likely to feel that mask-wearing would be appropriate in the virtual environment. The reason behind these findings may be participants' general resentment toward mask-wearing policies, or the feeling that viewing experiences were generally safe, without the sensation of being exposed to infectious diseases. This is supported by the lack of significant differences between viewing conditions in terms of disease exposure.

As pointed out earlier, there is a lack of understanding of the social implications of bodily proximity in relation to a global pandemic. Regarding this aspect of virtual cinemagoing, we found that in-person viewing in the second year of the Covid-19 pandemic did not pose more fear of the viewing circumstances not being safe or would mean disease exposure than VR viewing. This is interesting especially in regard to that VR viewing meant no less social experience than screen viewing.

4.1. Limitations and future research

While many of our findings corroborate prior results, we cannot rule out that any of these derive from the methodological weaknesses that such an initial, exploratory study would involve. Given the lack of previous research in the field of social virtual reality cinema environments and viewing experiences, further investigations are necessary to confirm the generalizability of our results in terms of VR cinemas' effects on film experiences, collective viewing, health, and well-being. Thus, we suggest treating our findings as potential hypotheses for future research, rather than generalizable conclusions.

Future investigations are proposed by adjusting the study's design, film stimulus, and the set of measures—for instance, by updating survey items and involving physiological measures to reflect on elements like emotional engagement and comfort/discomfort. Future studies may also consider allowing participants to reflect on their potential social experiences with digital avatars that are non-human users. Our participants were unaware that the viewing companions in VR were NPCs which implied neither that they are real people nor that they are not. Our reasoning behind this is that social VR applications generally involve human users behind avatars so it is unlikely that users would assume otherwise unless it is specifically suggested. While our results show that participants treated VR avatars as real viewing companions (by reporting strong social sensations and feeling of being in an environment with others), the representation and behavior of avatars may be raised in subsequent studies.

In addition, the mixed design used in this study meant that participants acted as their own control groups: participants in two of the four conditions were chiefly the same persons, whose reactions were recorded in the other screening environment, social setup, and using the other film sequence. While the order of exposure was randomized and counterbalanced, results may have captured biases due to sequential effects or repetitions.

Another limitation is that we used short sequences of a feature film to reduce exposure time and the duration of the experiment. But this means that the effects we captured may differ from those after watching an entire feature film—which would be a likely scenario for movie watching in co-viewing environments or even in virtual cinemas. Moreover, in this experiment, we did not measure or correlate the immersive qualities of the virtual and in-person viewing setups. Future research is necessary to investigate whether viewing experiences in VR cinemas would correspond to physical-world cinemas—ones with similar layouts, designs, sizes, and lighting, sound and image qualities. Besides directly measuring the effects of virtual and physical-world cinemas, future studies can compare simulated private spaces in VR (such as a virtual living room) with non-cinematic co-viewing spaces. In both cases, real-world counterparts would be marked by differences in décor, lighting, and atmosphere, as well as other affordances of these spaces, such as potentials to consume food and beverage. These were not replicated in the current study, and measuring more dispersed social effects compels a larger scale of study with additional controls. It would likewise be beneficial for future studies to introduce conditions for interactivity of human-controlled avatars within the VR social experience, in lieu of or as well as NPCs that appear as co-users. This again introduces social complexities and technical challenges, including parameters of design that shape possibilities for socializing and inducements, that are not controlled for in our own experimental design.

5. Conclusions

This study focused on the emerging phenomenon of watching movies in simulated cinematic environments in social virtual reality. Its point of departure was the challenges of in-person activities during lockdown measures, and we argue that movie spectatorship needs to be reconsidered in circumstances when social engagements are limited. In addition, the study was designed to provide methodological solutions and conclusions that can be considered in the user experience design of immersive applications for various social experiences and environments. While watching movies is no longer tied to cinemas or specific viewing spaces due to the variety of screening devices, we found evidence that VR cinemas can evoke experiences that are generally related to the kinds of co-viewing that movie theaters have fostered, such as the sense of community or presence. This way, VR cinemas can offer different kinds of immersive and social experiences to other commonly used screening devices in domestic settings, such as televisions, computers, or mobile devices—even though VR's accessibility is still generally more limited.

Supporting the assumption that virtual cinema can serve as an alternative to physical-world collective viewing, we found that viewing conditions do not impact the general impression of a movie, its emotional effects, and narrative empathy. The results also showed viewers' corresponding social experiences and level of comfort regarding disease exposure during virtual or in-person viewing. However, we observed that VR viewing produces higher evaluative ratings for the sense of narrative and physical presence. We also found that social viewing may lead to less engagement and more distractions

depending on the screening environment.

To detect whether media use habits, personality traits, or technology acceptance would affect these results and facilitate or hinder an engaging and pleasant viewing experience in virtual cinemas, we also compared participants' backgrounds and attitudes on these matters with their responses following VR viewing. Surprisingly, we found negative correlations between previous virtual reality exposure and comfort and well-being, whereas frequent cinemagoing, or preferences for cinemagoing, predicted more distraction and less engagement in the virtual screening room.

Those who are fascinated by technology were more likely to enjoy the movie, empathize with fictional characters, and accept the virtual environment as natural. Viewers' support of the idea of virtual cinematic experiences also predicts enjoyment as well as narrative presence, physical presence in the viewing environment, and the sensation of social experiences. Additionally, early technology adopters were less likely to feel disoriented in the virtual environment.

CRediT authorship contribution statement

Kata Szita: Conceptualization, Methodology, Formal analysis, Investigation, Project administration, Funding acquisition, Writing – original draft, Writing – review & editing. **Wyatt Moss-Wellington:** Methodology, Investigation, Writing – original draft, Funding acquisition. **Xiaolin Sun:** Methodology, Investigation. **Eugene Ch'ng:** Methodology, Investigation, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Dr. Kata Szita is a Marie Skłodowska-Curie research fellow at the ADAPT center of Excellence for AI-Driven Digital Content Technology and Trinity Long Room Hub Arts and Humanities Research Institute, Trinity College Dublin. Her research involves the cognitive studies of immersive digital media technologies and she has published research on attention, recollection, narrative engagement, and social behavior in terms of smartphone spectatorship, augmented reality, cinematic virtual reality, and social virtual reality. Currently, she leads interdisciplinary and cross-sector research on user experiences in social VR and AR and is involved in studies of cognitive processing of fictional information and digital personas.

Dr. Wyatt Moss-Wellington teaches film and writing studies at the University of Sydney. He is the author of Cognitive Film and Media Ethics (Oxford UP, 2021), Narrative Humanism: Kindness and Complexity in Fiction and Film (Edinburgh UP, 2019) and co-editor of ReFocus: The Films of Spike Jonze (Edinburgh UP, 2019). Moss-Wellington is also a progressive folk multi-instrumentalist and singer-songwriter with four studio albums: The Kinder We (2017), Sanitary Apocalypse (2014), Gen Y Irony Stole My Heart (2011) and The Supermarket and the Turncoat (2009).

Xiaolin Sun is a second-year doctoral student at the School of International Communications, the University of Nottingham Ningbo China. Working across cultural anthropology, museum studies, and digital heritage, Xiaolin is researching to examine an intersection between digital technologies and traditional ethnic minority artefacts. During his academic journey, Xiaolin participated in several conferences to present his research. He was also invited to Sichuan Fine Arts Institute to give two lectures on arts and advanced digital technologies. Prior to Nottingham, he collaborated with Dr Catherine Nichols at Loyola University Chicago on a digital humanities research project, *East Asian Textiles*.

Prof. Eugene Ch'ng is the founding director of the NVIDIA Joint-Lab on Mixed Reality focused on the use of digital technologies for culture and heritage at the University of Nottingham's China campus. He is co-editor-in-chief for MIT Press' PRESENCE journal, the longest established journal for VR research. He holds a number of international grants and serves in international conference committees in digital heritage and virtual systems.