We’re In This Together:

Embodied Interaction, Affect, and Design Methods in Asymmetric, Co-Located, Co-Present Mixed Reality

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ABSTRACT

Head-mounted immersive media (XR) places challenges on our ability to "cope skillfully,"[1] with what we encounter. Experientially, these technologies layer content, muddle our perception, re-orient our body in space, and can even seem to contradict laws of physics. They mediate the experience of our own bodies and interactions with others. These qualities make XR difficult to negotiate, as our bodies, both physiologically and cognitively, are directly implicated. Investigating XR from the lens of embodied interaction, this thesis defines and examines a particular social (i.e. multi-participant) manifestation of XR: *asymmetric, co-located, co-present, mixed reality* (ACLCPMR), and identifies key elements of embodied and relational experience within this medium.

Addressing a gap in current research regarding the affective nature of embodied interaction in XR, this thesis advocates for socially and physically mindful XR experiences, and formulates relevant design methods and considerations for future XR designers. An ACLCPMR design probe, *Wake*, and corresponding findings from a user study (N = 25) are presented. *Wake*, a social experience for one participant in-headset, one dancer, and one facilitator, uses a combination of an HTC Vive headset, Vive trackers, and an Intel RealSense depth camera to allow a participant to perceive virtualized real-time renderings of, and collaborate in simple movements with, a live, co-located, co-present dancer.

Trust in co-present head-mounted XR, a key emergent theme from the user study, is examined from the perspectives of embodied and social interaction, and human-machine mediated communication. The study utilizes the proxemics framework in real-world units, semi-structured phenomenological interviews, and two standardized metrics for identifying key cognitive experiences, emotions, and intersubjective relationships with co-present parties.

KEYWORDS: extended reality (XR), virtual reality (VR), mixed reality (MR), embodied interaction, immersion, media psychology, social psychology, proxemics, affect, embodiment, trust, relational, co-presence, co-located, design probe, user study, phenomenology

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[1] Dreyfus Hubert ,"Skillful Coping: Essays on the phenomenology of everyday perception and action", 2014.

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Glossary

In order to establish a consistent definition for some concepts which could have multiple interpretations, we define these key terms:

Extended Reality (XR): all hybrid virtual-and-physical environments, i.e. virtual reality (VR), augmented reality (AR), and mixed reality (MR)

Mixed Reality: real world and virtual content combine to form hybrid environments in which digital and physical elements interact

Co-Located: in the same physical space as others

Co-Present: both a mode and a sense of being with others

Embodiment: how bodily and cognitive processes are inseparable

Situated: how a situation and its context are related

Relational: how a relationship is articulated between people

Affect (psychology): the experience of emotion

Trust: 1. belief in a situation or person through conscious choice or the absence of fear
2. mutual reliability established as a consequence of direct action

1. Introduction

1.1 Situating the Thesis

1.1.1 Defining ACLCPMR

Head-mounted immersive media (XR[2]) places particular challenges on our ability to "cope skillfully"[3] with what we encounter, phenomenologically speaking. Experientially, these technologies layer content, muddle our perception, re-orient our body in space, occasionally contradict laws of physics, and mediate our experience of our own bodies and interactions with others. These qualities make it difficult to negotiate, as our bodies and senses are directly implicated. Thus, head-mounted XR is fundamentally embodied. Embodied interaction[4] is an approach to the design and use of computational systems which privileges sensory perceptions and physically engaged responses. This thesis investigates social XR from the lens of embodied interaction, identifies key elements of embodied experience in XR, defines and examines a particular social manifestation of XR (ACLCPMR[5]), articulates findings from a user study (N = 25) in which participants experienced ACLCPMR, and formulates relevant design methods and considerations for future XR designers in the development of socially and physically mindful XR experiences.

This thesis centers a particular manifestation of social, multi-participant head-mounted XR: asymmetric, co-located, co-present mixed reality, or ACLCPMR. In asymmetric, co-located, co-present XR, not all participants wear a headset, but everyone involved can interact and are tracked within the virtual environment. The addition of mixed reality (MR) implies a hybrid environment, in which elements of the real world (such as physical objects, architecture, or other people) intersect with the virtual world. Through this mediated, shared experience straddling physical and virtual environments, ACLCPMR most directly implicates, and should consciously incorporate, an embodied approach to design. As computational theorist Paul Dourish states, an embodied approach is "not a specific form of technological design; it is a stance we can take on the design of interactive systems"[6] - and thus, a value system.

With this value system in mind, I created *Wake*, a room-scale XR experience for one person in-headset, who is guided both physically and virtually by two co-located people: a dancer, who is tracked and can interact with the virtual environment, and an untracked facilitator. Created in collaboration with Pittsburgh-based experimental dance duo, *slowdanger* (Anna Thompson and Taylor Knight), *Wake* is an ACLCPMR experience using the HTC Vive virtual reality system, Vive trackers, and an Intel RealSense depth camera. This thesis will examine *Wake* in-depth, and present findings from a phenomenological user study to identify and understand particular design elements, such as experience facilitation and flow, virtual spatial design, and embodied, tangible interactions. These elements in turn influence emotional state, perception of and communication with others, freedom of movement, and trust within a mediated, hybrid environment.

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[2] XR, or "extended reality" encompasses the more specific VR (virtual reality), AR (augmented reality), and MR (mixed reality). Please see Glossary for a definition of these terms.
[3] By "cope skillfully" I am referencing Hubert Dreyfus' use of the term regarding our interactions with everyday, mundane objects and situations. However, I am also positioning myself within the critique of this argument in terms of the social and cultural context being inseparable from the ways we interact with and through technologies. I also want to acknowledge that I am early on in becoming aware of this critique and so there is much more to learn here.
Dreyfus Hubert ,"Skillful Coping: Essays on the phenomenology of everyday perception and action", 2014.
[4] Dourish, Paul. *Where the Action Is: The Foundations of Embodied Interaction*. MIT Press, 2001.
[5] Asymmetric, co-located, co-present mixed reality (ACLCPMR). This will be defined later.
[6] Dourish, Paul. *Where the Action Is: The Foundations of Embodied Interaction*. MIT Press, 2001. p 145.

1.1.2 Co-Location and Co-Presence in Daily Life

We experience many manifestations of both co-location and co-presence in our daily lives. One does not necessarily require the other, however, as shown by these two examples.

We are co-located when we are in the same physical space as others.

[7]

For example, people on the subway are co-located.

However, as the image above makes clear, each person is involved in their own solo task, reading, listening to music, or using a mobile device. None of these people are interacting with one another. They are co-located, but not co-present.

We are co-present when we share experiences with others. Thanks to the channels of real-time communication provided by technology, such as talking on the phone, or telepresence through video-chat, we can be co-present without being co-located.

For example, telepresence allows physically distant friends, loved ones, and colleagues to see and communicate with each other in real-time. For an increasingly globalized society, telepresence has helped create and maintain connections and share knowledge and experiences across vast distances and increasingly mobilized populations.

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[7] Image credit: Ourit Ben-Haim, http://undergroundnewyorkpubliclibrary.com/image/48044859694, Accessed December 04, 2018.

[8]

Image: Selena Gomez and Justin Bieber are co-present via smartphone.

Whether mundane or transformative, social experiences often involve being both co-located and co-present. The ability to perceive and respond to another person when we are in the same physical space with them, unmediated, through eye-contact, both body and verbal language, and shared physical objects or experiences (i.e. cooking together, playing sports, dancing), is a fundamental part of human society. Shared rituals and experiences, such as celebrations, religious and secular ceremonies, and going to school, create memories and mark important rites of passage and stages of life. We can have both commonplace and very powerful experiences when we are together.

Increasingly, though, technologies of mediation (smartphones, screens, headphones, etc) are infiltrating our social, professional, and intimate co-located experiences. Not just strangers on public transportation, but strangers in our own homes, we mediate our time with others, and create barriers to being present together. However, creating powerful or engaging co-located, co-present experiences that involve various forms of mediation could describe many cultural and entertainment experiences - i.e. theme parks, music festivals, immersive theatre, etc. For an industry still finding its feet, the creation of location-based, co-present XR experiences could take advantage of what is powerful about both worlds.

We live in an age when digital information is increasingly enmeshed into our physical and social lives. As literary critic and feminist cybernetic theorist N. Katherine Hayles states, “[e]mbodied experiences are changing in information-rich environments.”[9] The combined effects of the smartphone and social media, both introduced within the past 15 years, have brought about a seismic shift in the ways we communicate with each other and navigate our

[8] Image Credit: @jelena.videomanips
[9] Hayles, Katherine N. “Flesh and Metal: Reconfiguring the Mindbody in Virtual Environments.” Configurations, Volume 10, Number 2, Spring 2002, pp. 297-320.

environment. Through much speculation and hype, and burgeoning evidence[10], head-mounted XR is positioned on the precipice of a similar societal transformation.

If head-mounted XR is to fulfill its promise of expansive, connective, fantastical, and empathetic experiences, and not become simply another method of mediated separateness, or worse, an irresponsible, careless medium for violent or triggering content, we must examine its effects and consciously identify the ways in which we can design experiences with care.

Co-located, co-present XR experiences engage issues of trust within shared experiences in which both physical and social interactions are filtered through different sensory channels of mediation. Trust is a fundamental element of human existence as a society of interdependent individuals. Establishing and maintaining trust is necessary for communication and relationships. Trust can be articulated from multiple perspectives, but two important concepts will be examined here: trust as manifest through embodied knowledge, and trust as a consequence of repeatability.

1.1.3 Towards a Different Vision of XR: Inclusive, Embodied Practices For Knowledge Creation Within Technology Development

In her 1988 essay, “Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective,”[11] cybernetic feminist theorist Donna Haraway questions the empiricism of the “real” as defined by a limited group of ratified “experts.” Here, she lays the groundwork for the creation of inclusive technology research communities which seek out and value knowledge from traditionally excluded communities and expertise. Haraway’s insistence on the value of first-person and marginalized perspectives in the process of scientific knowledge creation articulates an ethics of “objectivity” that is greatly needed in a society increasingly driven by “black-box” technologies such as AI and robotics. Specifically calling into question the Western sense hierarchy and a false notion of “passive vision,” Haraway argues for the inseparability of vision from other embodied senses which contribute to the creation of meaning and knowledge - specifically a scientific “objectivity.” Regarding vision, power structures, and agency, she states, “I would like to insist on the embodied nature of all vision and so reclaim the sensory system that has been used to signify a leap out of the marked body and into a conquering gaze from nowhere.”[12]

The expanded dialogue and inclusive perspective articulated by Donna Haraway should play a crucial role in the development of new technologies and processes which directly implicate our bodies, our interactions with others, resulting power dynamics, and our evolving value systems. As Haraway states, “[i]n the history of science we have often seen the design of technology outpace our understanding of the principles that make the technology function.”[13] Research and development, as well as public dialogue, should incorporate cross-disciplinary participation from practitioners whose knowledge and expertise is crucial to, yet often missing from innovation trajectories for emerging technologies. For XR and other spatial computing experiences, this should include dialogue from experts on the impact of technology on social structures, interpersonal communication, and physical and mental health. Input is crucial from marginalized communities, participation from artists, and other stakeholders whose perspective is often not considered in favor of the often self-anointed “experts,” within a circumscribed echo

[10] Bailenson, Jeremy. *Experience on Demand.* 2018.
[11] Haraway, Donna. "Situated knowledges: The science question in feminism and the privilege of partial perspective." *Feminist studies* 14.3 (1988): 575-599.
[12] Haraway, Donna. "Situated knowledges: The science question in feminism and the privilege of partial perspective." *Feminist studies* 14.3 (1988): 575-599**.**
[13] Frank Biocca; The Cyborg's Dilemma: Progressive Embodiment in Virtual Environments , *Journal of Computer-Mediated Communication*, Volume 3, Issue 2, 1 September 1997, JCMC324, https://doi.org/10.1111/j.1083-6101.1997.tb00070.x

chamber situated in Silicon Valley. The current limited perspectives involved in the development of this technology have created scenarios in which potentially harmful interaction design methods and content creation strategies go unquestioned and become ratified as canon.

Head-mounted XR experiences, especially those which are multi-participant, walkable, and incorporate mixed reality, are a particularly current and increasingly relevant example of a technology which needs to be acknowledged and examined as impacting our embodied, social selves. This is where I see value in engaging in collaborative practices with dance and movement artists and practitioners. My collaboration with *slowdanger* served as a test laboratory for exploring embodied interaction within head-mounted experiences, and the design probe, *Wake,* resulted from a deep and sustained creative and theoretical dialogue which emerged between us, through physical movement, interaction design experiments, and discussion.

Haraway, in a way predicting the influx of devices which cover, or transform our eyesight - such as VR/MR/AR headsets - argues: "The 'eyes' made available in modern technological sciences shatter any idea of passive vision; these prosthetic devices show us that all eyes, including our own organic ones, are active perceptual systems, building on translations and specific ways of seeing, that is, ways of life. There is no unmediated photograph or passive camera obscura in scientific accounts of bodies and machines; there are only highly specific visual possibilities, each with a wonderfully detailed, active, partial way of organizing worlds. All these pictures of the world should not be allegories of infinite mobility and interchangeability but of elaborate specificity and difference and the loving care people might take to learn how to see faithfully from another's point of view, even when the other is our own machine. That's not alienating distance; that's a possible allegory for feminist versions of objectivity. Understanding how these visual systems work, technically, socially, and psychically, ought to be a way of embodying feminist objectivity."[14]

1.1.4 Physiological Inaccessibility and Limited Audience

Image: KAT WALK, Kat VR treadmill

Despite much hype around the transformative powers of virtual reality to promote empathy and travel to uncharted territory, many existing commercially available XR experiences are physiologically inaccessible[15], require literacy of (often violent) video games, and are not sensitive to a majority of phenomenological experience of the participants. These factors, among others such as cost prohibition, hardware limitations, and homogenous available content, contribute to the reduction of mass access and appeal. Thus, audiences remain limited, far below industry expectations.[16] This image to the left, shown on a Forbes article[17] which discusses how, and if people will make money with VR, plainly illustrates (even if this is not the aim of the article) one of the biggest problems with the perspective of the industry. In addition to being expensive, bulky hardware, this is not the image of an embodied, mixed reality future, or even an afternoon's entertainment, that many would want to envision. Additional factors, such as shifting investment trends, signals from heavyweight companies such as Apple, Facebook, and Google, and predicting consumer desires for content and experiences all affect adoption within this emerging market. Regarding experience and content design, if the industry maintains a limited perspective, only an equally

[14] Ibid. 583.
[15] https://www.cnn.com/2017/12/13/health/virtual-reality-vr-dangers-safety/index.html, Accessed October 11, 2018.
[16] https://uploadvr.com/sony-psvr-still-selling-industry-growth-slower-expected/, Accessed October 11, 2018.
[17] https://www.forbes.com/sites/charliefink/2018/01/02/how-are-people-making-money-in-vr-or-when-will-they/#3e5129bc75d7, accessed December 5, 2018.

limited audience will be reached.

I do not want to convey the idea that XR experiences which incorporate violent scenarios are always inherently bad, because I do not believe this. However, I do believe that XR must address real-world issues of human communication, emotion, and sensation with the breadth and sensitivity of any other art form that ventures to reach a mass audience. In other words, we should resituate and expand knowledge creation and design methods within technology development.

1.1.5 Research Questions and User Study with Design Probe

The relationship between cognition and action is central to my research. A significant barrier to entry with immersive head mounted experiences is a lack of access to them in the first place, but also an absence of the context to understand or interrogate these processes. How do we discuss virtual experiences? What language do we use? How do we talk about the ephemeral, "feeling" ways we perceive these experiences? How can taking a developmental, cognitive science perspective on human communication and social psychology help us understand multi-participant virtual and mixed reality experiences? How can a mixed reality experience, incorporating concepts of tangible and social computing, be successful? What defines success? How do people experience these phenomena in VR/MR?

In the following chapters, the discussion of my ACLCPMR design probe, *Wake*, will work towards understanding an experience which prioritizes and endeavors toward an accessible, physiologically and psychologically inclusive experience.

The next chapter will articulate the background research which situates the creation of *Wake* within a Science and Technology Studies (STS) lineage and theoretical dialogue. I will also examine my own previous research experiments which generated both technical and conceptual insights, further explored in this thesis project.

2. Background

2.1 History Lesson From Half A Century Ago

During the process of writing of this thesis in 2018, we are on the verge of what stands to be another significant shift in the media landscape as XR technologies are more powerful and widely available than ever.

To set the stage for a discussion of embodied interaction in immersive media, we'll briefly look back exactly 50 years ago, to 1968. Two contemporaneous practitioners explored a concept of extended (or augmented) vision: the Brazilian Neo-Concrete artist Lygia Clark, and the American virtual reality researcher Ivan Sutherland. They both created a scenario and device for an out-of-the-ordinary interaction through sight, and immersion in a specifically situated scenario - one is social, and the other solo. Both questioned our understanding of how we position ourselves within, and relate to the world, by either focusing our attention on the eyes of another person, or layering our vision with computer generated imagery.

Lygia Clark created a series of sculptures and devices she called *Relational Objects*, which were not meant for display as art objects, but were activated by interaction. Her 1968 work, *Oculos Dialogos*, is part of this series, and is enlivened through direct participation by two people who wear the device together. These two people are "situated," physically and socially, in relationship to each other, and engage in an intimate eye-contact dialogue through the goggles. Their movement is restricted by the device, but can extend or compress the space between them by a matter of inches, using the metal structure built between the eye pieces. In the study of proxemics, or the human use of interpersonal space (which will be discussed in depth later), this interaction takes place firmly in intimate space. This work uses only the technology of physics and mechanics, yet it is certainly in dialogue with the world of optics, human-machine (cyborg) interactions, and alludes to the telematic future that was to come.

That same year, computer scientist, internet pioneer, and "father of computer graphics," Ivan Sutherland, created the first head electronic mounted display (HMD) for virtual reality at MIT. He named it, *The Sword of Damocles,* for the Greek story of the man in the lap of luxury, with a sword suspended by a hair dangling over his head. Sutherland's device was very heavy and required specific positioning to track head movements, necessitating it to be hung from, and supported by, the ceiling in order to be worn. Though the graphics were simple wireframe rooms, primitive renderings for what we now expect from virtual reality, this first electronic, stereoscopic HMD allowed a user to feel a sense of presence and first-person immersion in a 3-D world of computer generated imagery for the first time.

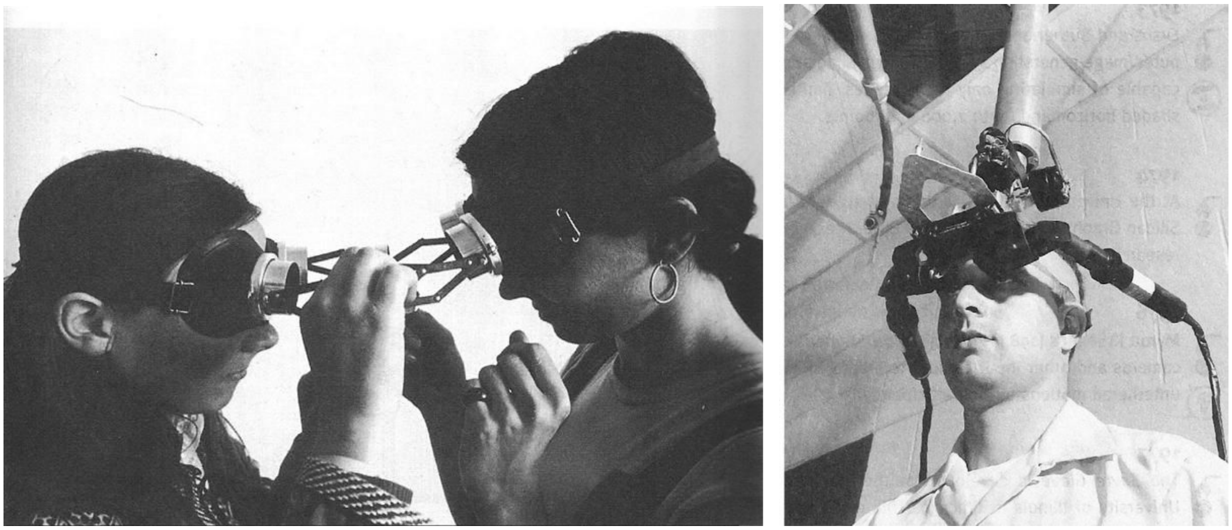

Figure 1.
(Left) Lygia Clark's *Oculos Dialogos,* 1968, from her series *Relational Objects*[18]
(Right) Ivan Sutherland's (MIT) *Sword of Damocles*[19], 1968, the first electronic head-mounted virtual reality display.

These are two instances of contemporaneous, but very differently valued ways of augmenting vision or focusing attention on other worlds - either the world contained in another person's eyes, for Clark, or, for Sutherland, the world of limitless possibility as a solo traveler, into digitally created otherworlds.

Both pieces are situated in specific context, directly implicate the participants bodies (re-orienting ourselves to our familiar senses using devices which physically attach to our bodies), and privilege interactivity to activate the devices and participant experiences. But they communicate vastly different priorities, research interests, and visions of embodied interaction within society. These works have both influenced my own research significantly, in terms of my thinking about the effects of head-mounted devices on our sense of being co-present with another person, and in working towards an intentionally relational experience with the affordances and possibilities of emerging technologies.

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[18] Osthoff, Simone. "Lygia Clark and Hélio Oiticica: a legacy of interactivity and participation for a telematic future." *Leonardo*30.4 (1997): 279-289.
[19] Ivan Sutherland

2.2 Theory Framework

2.2.1 Phenomenology and XR

Phenomenology examines human consciousness from the perspective of a subjective awareness of physiological and mental processes within direct experience. In other words, phenomenology is concerned with our lived experience with the everyday world, and positions the body and first-person experience as central to knowledge and meaning-making.

Heidegger, one of the primary philosophers of phenomenology, used the term “Dasein[20]” to mean “being-in-the-world,” or, in essence, presence. Presence is an embodied sense of one’s self-location, gained through the unification of physical and cognitive perceptions. Many scholars and creators of VR foreground the believable sense of presence as one of VR’s most powerful qualities. Contributing crucially to a sense of immersion, presence can help un-mediate the mediated, or as Lombard, et. al.[21] describes, convey to a user that a technologically created simulation is actually real. A strong sense of presence in an XR experience can be gained through authentic social interactions, graphical and audio fidelity, and user agency to affect the virtual environment.[22]

In his 1945 book, “The Phenomenology of Perception, French philosopher and psychologist Maurice Merleau-Ponty articulated a philosophy of the perceiving body. Hubert Dreyfus, a Merleau-Ponty scholar, refers to the process of encountering and responding to the world around us as a constant attempt at “skillful coping” with what we experience.[23] This coping with direct experience is always oriented towards an object, whether that is something, someone, or some environment. The contemporary queer theorist Sara Ahmed brings the question of orientation into dialogue with phenomenology, critically examining how we arrive at an orientation. She brings the particularity and specificity of different perspectives, other than that which was assumed to be all-encompassing as Merleau-Ponty and Dreyfys intimated, into the question of experience and phenomenological response. In this way, she is in dialogue with the work of Hawaway’s *Situated Knowledges*. Specifically, Ahmed discusses affect, emotion as intentional and directed towards an object - our encounter with an object, but also how and why we turn towards (or away from) it.[24] In other words, what personal, specific experiences, identities, and phenomenological responses impact the ways we meet the objects, scenarios, and our interactions with the world?

The phenomenological perspective poses particularly interesting implications for the understanding of and design of cognitively demanding (i.e. high cognitive load), social XR experiences. Many scholars of XR use a phenomenological approach due to the experiential nature of immersive experiences, i.e. the importance of direct interaction, user agency, and felt physiological and psychological phenomena within a situated environment that crosses virtual and physical boundaries. What has been largely missing from this phenomenological examination of XR, however, is an inquiry into affect and emotional intentionality within these immersive experiences, and the ways in which interaction and experience design can amplify or mitigate certain emotional scenarios.

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[20] Heidegger, Martin. "Being and time. 1927." *Trans. John Macquarrie and Edward Robinson. New York: Harper* (1962).
[21] Lombard, Matthew, and Theresa Ditton. "At the heart of it all: The concept of presence." *Journal of Computer‐Mediated Communication* 3.2 (1997).
[22] Adapted from Lombard, et. al. cited in Tham, et. al.
[23] Dreyfus, Hubert. Ibid.
[24] Ahmed, Sara. *Queer phenomenology: Orientations, objects, others*. Duke University Press, 2006.

2.2.2 Embodied Interaction

I understand *embodied interaction* to mean the ways we perceive and respond to interactive systems. Two thinkers who provide a framework for my discussion and investigations into embodied interaction are the computational theorist Paul Dourish, and the literary critic and cybernetic feminist N. Katherine Hayles.

Paul Dourish, in his book *Where the Action Is: Foundations of Embodied Interaction,* discusses embodiment as grounded in the lineage of the philosophy of phenomenology. As of the writing in 2001, Dourish sees embodied interaction manifesting in the development of hybrid mediated environments rooted in tangible and social computing. He states, "[e]mbodiment denotes a form of participatory status."[25] Participation and communication through direct interaction within mediated experiences and computational systems is strongly implicated in CLCPXR experiences. The notion of embodiment is in relationship to technology can mean many things, but what I wish to highlight about Dourish's position on embodied interaction, which I see my work in direct lineage to, is a particular holistic approach to the very process of design, rather than simply a focus on the final output. As Dourish argues,"[w]hat I am claiming for 'embodied interaction' is not simply that it is a form of interaction that is embodied, but rather that it is an approach to the design and analysis of interaction that takes embodiment to be central to, even constitutive of, the whole phenomenon."[26] Through developing the work in an embodied, improvisational manner, in collaboration with slowdanger, the design process sustained a similar "listening" technique, and awareness of our own affective, physical, and social responses activated by the ACLCPMR scenario we developed together. This approach to the evolving dialogue between technical capabilities, restrictions, and human responses helped to leverage the "familiar" and everyday embodied knowledge that we felt was missing from many other existing virtual reality experiences. Dourish importantly draws a distinction between simply physical embodiment and other forms of embodied experience, saying, "Certainly, embodiment retains this notion of immanent 'presence,' and of the fact that something occurs in the world; but it need not rest on a purely physical foundation. Embodiment extends to other phenomena that unfold directly in the world; conversations, mutually engaged actions, and so on."[27]

Cybernetic feminist theorist N. Katherine Hayles states, "Especially in times of rapid technological innovation, there are many gaps and discontinuities between abstract concepts of the body, experiences of embodiment, and the dynamic interactions with the flux of which these are enculturated expressions."[28] I believe this is true now of evolving rhetoric and experiences developed for head-mounted immersive media.

Both theorists are in dialogue with the lineage of phenomenology, which foregrounds a first-person perspective of bodily, lived experience, rejects Cartesian mind/body duality, and understands cognition as fundamentally embodied.

Understandings gained from the embodied interaction framework articulated by Dourish regarding tangible and social computing, and human-machine situated relationships articulated by Hayles and Haraway, provide a strong platform for an examination of the immersive, embodied, and relational qualities of multi-participant, co-located XR. Now, as the technologies are more readily available and financially backed than ever before, is a crucial time for this critical examination to take center stage.

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[25] Dourish, Paul. *Where the action is: the foundations of embodied interaction*. MIT press, 2004.
[26] Ibid, p. 102.
[27] Ibid, p. 100.
[28] Hayles, Katherine N. "Flesh and Metal: Reconfiguring the Mindbody in Virtual Environments." Configurations, Volume 10, Number 2, Spring 2002, p.304.

2.2.3 Key Framework: Proxemics

One framework for understanding and sense-making from the user data collected is the field of Proxemics[29], or the human use of interpersonal space, broken into four zones: public, social, personal, and intimate. These zones are measured quantitatively, and have different measurements in various countries, as personal space is conceptualized differently across cultures. We used the measurements for the United States of America. Proxemics was developed by Edward T. Hall as a part of the growing presence of the field of social psychology in the 1960's.

Interpersonal distance in virtual environments has been examined by Jeremy Bailenson, et. al.[30] but only in reference to virtual co-presences of computer generated avatars. *Wake* involves other real people, who are both co-located and co-present. Therefore the proxemics measurements are based on real-world locations perceived through a mediated ACLCPMR experience.

Figure: Proxemics illustration, showing measurements for public space, social space, personal space, and intimate space

[29] Hall, Edward T., *The Hidden Dimension*, 1966.
[30] Bailenson, Jeremy N., et al. "Interpersonal distance in immersive virtual environments." *Personality and Social Psychology Bulletin* 29.7 (2003): 819-833.

2.3 Precedent

Char Davies, *Osmose*

A discussion of embodiment in virtuality would not be complete without a mention of the artist and researcher Char Davies, whose VR piece *Osmose*[31], from 1995, did not use controllers, but used a breathing sensor worn at the chest of the user to allow them to navigate the virtual environment, which reflected a natural landscape with trees and roots. This piece, through embodied interaction, directly implicates and empowers the user's body in a merging of physical and virtual.

Images: Char Davies, *Osmose* (1995)

Simon Penny, *Traces*

Traces is a project for networked CAVEs (immersive VR spaces), created in 1999. The focus is real-time spatial/bodily interaction between distant participants via real-time 3D image (and sound) traces[32]. The mapping of a participant's movements to visual traces in an immersive environment is similar in style to how we used the dancer particle and especially the path at the end which was revealed to the user. "The trace avatar, Penny and his collaborators write, 'must be thought of as the part of the system which is intimately connected to the user. In this way, the line between system, avatar, and interface also becomes blurred; the avatar becomes the interface, the point at which the computational system and the user make contact."[33]

Images: Traces, Simon Penny, 1999

[31] Davies, Char, and John Harrison. "Osmose: towards broadening the aesthetics of virtual reality." (1996).
[32] Of note, the graphics and computer vision system were developed at Carnegie Mellon University at The Studio for Creative Inquiry.
[33] Penny, Simon. Quoted in N. Katherine Hayles, "Flesh and Metal: Refiguring the Mindbody in Virtual Environments."

2.4 Current Examples of CLCPMR

Location Based Experiences

Location-Based Experience (LBE) is a recently-defined industry term for co-located, co-present mixed reality experiences, often involving elements of physical installation, live performance, and un-tethered participants wearing XR headsets. Often, haptics vests or other sensors worn on the body are incorporated. These experiences can have many manifestations — as cultural events, themed entertainment, branded content, or simulation / educational experience — and draw from elements of immersive theatre, cinema, theme park entertainment, live concerts, and in some cases, escape rooms or obstacle courses. LBE's are becoming increasingly popular[34] as the industry's bet for commercial return and a solution for the issue of consumers not purchasing expensive, bulky equipment or having the technological skills or physical space to stage this type of immersive experience in their homes. LBE's are also seen as a potential method for tie-in's to in-home experiences, which could potentially aid consumer adoption of XR technologies. The embodied and affective investigations and insights within the *Wake* user study, which will be discussed in the following chapters, have direct implications for the creation of Location Based Experiences.

Here are some current examples of both commercial and non-commercial applications of location-based, multi-participant, head-mounted immersive experiences.

The Void VR

Figure: The Void VR, *Ghostbusters: Dimension* Experience, 2017
Image Credit: The Verge

34 https://www.forbes.com/sites/moorinsights/2019/01/04/location-based-vr-the-next-phase-of-immersive-entertainment/#752beb473f57, Accessed Jan 5, 2019.

As described on Void VR website:
"It's hyper-reality. It's technical achievement. But mainly, it's fun! THE VOID is a whole-body, fully immersive VR experience, full of surprises at every turn; with you, your family and friends inside the action. One second you're standing on solid ground, the next you're stepping deep into darkness, looking at unimaginable beauty – or fending off danger from another realm. Did you see it? Did you feel it? What's next? You'll just have to experience it to understand."[35]

On a technical level, The Void produces experiences which integrate a custom designed physical environment with spatial/planar sensing. The experiences are often rooted in gaming, with theatrical elements and social or shared communication or tasks. The Void extends sensory perception in virtual reality to the physical environment, physiological or haptic feedback directly worn on the body of participants, and immersive audio. In other words, these experiences meet the definition of mixed reality (MR).

Regarding content, the majority of the available experiences produced by The Void draw from action/adventure movies or similar video game tropes or franchises. The Void is a fully commercial operation, which means it aims for mass appeal. While I do see the consumer draw of immersive adventure experiences, and especially tie-in's with commercially successful films, I am concerned regarding the close connection to military simulation training, value systems, potential for harmful embodied experiences, and very narrow scope of what is possible or could be commercially successful in the world of location-based CLCPMR experiences. If the perspective of "whole-body, fully immersive VR experience" and "action" is limited to gun or weapon-based interactions, this negates the vast majority of human experiences that could also be "whole-body" and "action" oriented. While The Void VR does not only create these types of experiences, the bulk of publicly available marketing and media that can be found about this organization shows multiple people, in-headset, holding guns.

Alice in Wonderland, Holojam


Images: Alice in Wonderland, Holojam
NYU Future Reality Lab, 2018

This project by the NYU Future Reality Lab is an example of a new kind of immersive, participatory theatre, or a location-based experience. Here, both actors and audience are tracked (using Vive trackers), and everyone is both co-located and co-present in this mixed reality experience. The actors control the virtual main characters, such as Alice and the Caterpillar, and the audience are immersed observers in the form of butterflies in the environment. This project is exciting to see the world of theatre and performance exploring co-present XR experiences. Theatre is deeply rooted in collective ritual, storytelling, and the importance and cultural function of live experiences, and this

[35] https://www.thevoid.com/, Accessed December 2, 2018.

perspective will be crucial in developing a different perspective on the possibilities for location-based co-present XR. The relatively recent massive popularity of immersive, participatory performance experiences like Punchdrunk's *Sleep No More*[36] demonstrates that audiences are ready and hungry for transformative, active, and information-rich experiences. The addition of XR technology has expansive potential, and I believe, mass appeal.[37]

2.4.1 Behavioral Abuses in Participatory, Immersive Experiences

The recent revelations that Punchdrunk's actors have been groped during shows[38] indicates that this immersive, participatory approach must negotiate the risks and behavioral offenses of a public who is, to a certain extent, uncontrolled, and must delineate clear policies, boundaries, and accountability for these abuses. The world of location-based, co-present XR experiences will (and has already no doubt) encounter a similar problem, and the industry is no exception to these responsibilities. Any reading on the abuses of VR Chat, trolls, and harassment, will show that the anonymity of an online VR experience can bring about deplorable behavior. The addition of co-location to a co-present head-mounted XR scenario, crossing the boundary between physical and virtual environments, and implicating physical safety of performers and participants, will require complex and careful implementation of behavioral rules and structures. For these reasons alone, the social psychology and structure of these experiences demands attention.

2.5 Empirical Studies

My research questions are interdisciplinary, and therefore the issues of embodied interaction, affect, and co-present relationality in head-mounted XR find relevance in empirical studies done across the fields of psychology and cognitive science, virtual reality, dance and movement studies, and human computer interaction.

Steed, et al.[39] studied cognitive load in VR, and found that users who had a self-avatar and were able to move their own hands increased letter pair recognition in a test, therefore lowering the mental load of the task. They point out the technical difficulty in creating an accurate self-avatar for a user, as most avatars now do not look like a user or are static. This is an issue that is solvable and may be helped by developments in using depth/scanning technologies like the Intel RealSense camera to represent the user's body in real time within the virtual environment. Additionally, this study points to the affordances of physical movement in VR which help in reducing the cognitive load. Both of these insights are relevant to concepts explored in Wake.

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[36] https://www.theguardian.com/stage/2015/mar/31/sleep-no-more-avant-garde-theatre-new-york, Accessed December 2, 2018. https://www.wsj.com/articles/interactive-theater-group-broadens-its-repertoire-1490299826, Accessed December 2, 2018.

[37] At the time of writing, theatre companies and hybrid theatre / mixed reality experiences are emerging, mostly accessible in industry events or festivals, such as The Future of Storytelling or the Sundance Film Festival. These experiences are often expensive to produce and have limited throughput (aka a small number of audience can experience them due to the equipment or technical needs. Creative and academic communities, as well as commercial industries are both developing (sometimes in tandem, sometimes at odds with each other) experiences which would fall under what is being labeled the "Experience Economy" in which these projects may find homes or receive production resources. This is a brief footnote for what deserves a deeper dive, and is very current in its relevance to the evolving nature of entertainment, education, and cultural output. Examples: https://www.marshmallowlaserfeast.com/experiences/ocean-of-air/, https://www.becomechained.com/, http://weareanagram.co.uk/project/the-collider/, https://www.warremains.com/home/#about, Accessed March 3, 2019.

[38] https://www.buzzfeednews.com/article/amberjamieson/sleep-no-more#.fnPV962E6, Accessed December 2, 2018.

[39] Steed, Anthony, et al. "The impact of a self-avatar on cognitive load in immersive virtual reality." *2016 IEEE Virtual Reality Conference (Vr)*. Vol. 23. IEEE, 2016.

Also studying the impact of avatars in VR, Bailenson, et. al.[40] studied user's proximity in virtual environments to humanoid avatars. Using the proxemics framework, the impact of a static humanoid avatar versus a humanoid avatar who walked towards a participant were studied. The study concluded that the participant maintained more distance from an avatar who engaged the participant in mutual gaze, versus the participant approaching a static avatar from the back. This is relevant to the emergent theme of perceived mutual eye contact (on the part of the participant) made between the dancer and participant in the Wake study, which was found to correlate with increased trust. Wake, however, uses representation of real people rather than a humanoid avatar. This study did use similar methods to the Wake study in terms of allowing a participant to familiarize themselves with a virtual environment on their own first before the entrance of a human representation.

In the field of cognitive and developmental science, Tomasello and Carpenter[41] argue for the process of shared intentionality in social-cognitive and social-motivational skill development in children, identifying behavioral transformations that are fundamental to human development. These transformations include "gaze following into joint attention, social manipulation into cooperative communication, and group activity into collaboration."[42] These behaviors could also be compared to studies of co-located co-presence in head-mounted XR. I feel that the process of negotiating social presence and shared activities in XR may go through a similar transformative process, and could benefit from an understanding of this developmental study of human behavior. I would not be the first to make the metaphorical connection that in VR we all become babies when we first put on the headset.

Related to shared intentionality, Himberg, et. al.[43] studied coordinated interpersonal behavior in dance improvisation, and describe a "kinesthetic togetherness" shared by the dancers. They articulate, "this active, kinaesthetic togetherness is more than just the joining of individual feelings or states of mind about a shared situation, it is the joining of actions, gestures, or movements in a shared situation."[44] Himber's analysis was influential in understanding the emergence of movement mimicry between the dancer and participant interactions, and the corresponding self-reported emotions in the Wake study.

Finally, Rae, Irene et. al[45] articulate design dimensions for understanding telepresence, which I found useful in formulating categories for analyzing the form of co-located co-presence we used in Wake. The Intel RealSense stream could be considered telepresence due to the real-time representation of the dancer, and the limited "window" or "screen" of this representation due to the field of view of the camera, the nature of which will be described later in the thesis. These categories detail a consideration of experience flow, physical environment, user mobility, how users see and focus attention, communication, and user autonomy. All of these categories are relevant to our study of ACLCPMR.

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[40] Bailenson, Jeremy N., et al. "Interpersonal distance in immersive virtual environments." *Personality and Social Psychology Bulletin* 29.7 (2003): 819-833.
[41] Tomasello, Michael, and Malinda Carpenter. "Shared intentionality." *Developmental science* 10.1 (2007): 121-125.
[42] Ibid. 121.
[43] Himberg, Tommi, et al. "Coordinated interpersonal behaviour in collective dance improvisation: the aesthetics of kinaesthetic togetherness." *Behavioral Sciences* 8.2 (2018): 23.
[44] Himberg et al., "Coordinated Interpersonal Behaviour in Collective Dance Improvisation." *Behavioral Sciences, 2018, 8, 23.*
[45] Rae, Irene, et al. "A framework for understanding and designing telepresence." *Proceedings of the 18th ACM conference on computer supported cooperative work & social computing*. ACM, 2015.

2.6 Preliminary Experiments

Sand VR

Sand VR utilizes real-time streaming depth data of kinetic sand to model a constantly changing mesh as manipulated by two co-located players in virtual reality. Virtual objects respond to this mesh and trigger simple game mechanics. The depth stream is captured with a Kinect V2, and is networked between two computers, streaming to two Oculus VR headsets. Sand VR is co-located, symmetrically co-present, explores playful tangible materials, encourages touch between participants, and explores mediated negotiation of darkness and collaboration. Sand VR was created in collaboration with Yujin Ariza.

This project was the most game-like of my preliminary experiments, and was inspired by the concept of "infinite games" as defined by James P. Carse.[46] He states, "[a] finite game is played for the purpose of winning, an infinite game for the purpose of continuing the play."[47] Sand VR was also inspired by artist Lygia Clark's *Relational Objects*, specifically *Air and Stone* (1968) and *Abyss Mask* (1968), which explored embodiment and participation using simple materials and highlighted senses other than vision.

In this project I explored creating a loose structure for an interaction between two players in VR, centered around an intuitive, familiar tangible material. Two players sit opposite each other at a table with a custom designed game board.

Figure 6. Sand VR custom game board; CNC routed MDF, 4 (four) steel plates.

Players physically mold kinetic sand in order to create pathways of movement for small, virtual spheres which would respond in real-time to the changing virtual mesh created by the physical sand.

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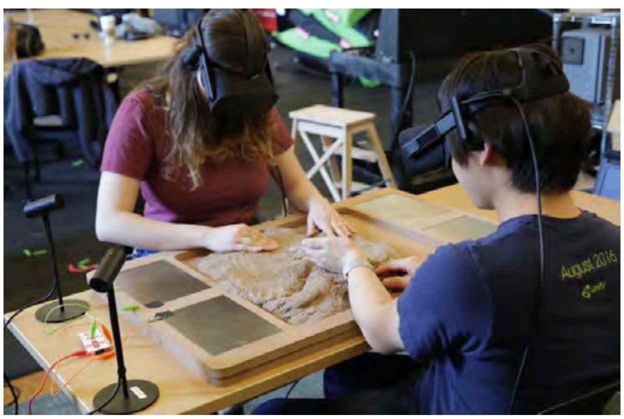
[46] Carse, James P. *Finite and infinite games*. The Free Press, MacMillan, Inc., New York, 1986.
[47] Ibid, p.3.

Figure 7. Views in player headsets, using Oculus Touch. Depth mesh rendered with rim light shader, virtual spheres visible, and virtual light triggered by player touch.



Figures 8, 9. Players molding sand (left); Players touch hands and metal plates which completes Makey Makey circuit, triggering a virtual light in game environment (right).

This project opened up many questions, some of which were further explored in Wake.

<u>Game Design</u>

Regarding infinite games, Sand VR explored the concept of a "soft reward" for interaction when the players would gather all the virtual spheres inside a "target" identified by a small light in the environment. The spheres move in a manner aiming to imply animacy from an abstract object, and when gathered at the target, the spheres erupt like fireworks, scattering to new corners of the environment to be guided again to a new target. Wake utilized a similar "soft reward" mechanic when players interacted with virtual spheres which released small lights into the environment. Sand VR also aimed to encourage collaboration between participants, but was also found to allow a space for parallel play, where the participants are adjacent to each other, but involved in their own sand play.

Interaction Design
Sand VR does not use traditional controllers, but uses physical materials (sand, metal) and the players' own bodies to interact with the virtual world. Real-time depth data and simple sensors (in this case, a Makey Makey) replace the controllers. This engages a player who may not have a background or familiarity with using controllers for video games, where other controller-based games may limit engagement to specific audiences. In this way, Sand VR may help promote inclusive virtual experiences.[48] Wake also enabled virtual interaction through physical interaction with tangible materials and co-located, co-present people, and used simple sensors (Vive trackers) to control virtual objects, and did not use controllers. Sand VR confirmed my idea that kinetic sand would be an engaging, intuitive material for participants, and Wake also utilized this material in addition to common play sand to encourage embodied interaction.

Sand VR used an interaction mechanic that was not entirely successful: using one hand to mold sand and keeping the other hand on a metal plate caused the touch between players to feel forced. Many players wanted to use both hands to mold the sand, so the concept of "accidental" or "surprise" illumination in the virtual environment did not work as well as planned. Perhaps a wearable device for each player that would not restrict movement, or using computer vision and machine learning to detect touches would eliminate this issue. Wake's use of Vive Trackers worn at the wrists sought to allow for the most freedom of movement, with a sensor that would function without being consciously engaged by the participant.

Darkness
In Sand VR, the players negotiated a darkened environment the whole time, with no visible "architecture" other than the shifting sand mesh. While I believe the darkness did help sensitize the players' sense of touch, and rely less on their visual senses, I think being in near total darkness was uncomfortable or confusing for some players, and the method of illuminating the virtual environment through touch was not intuitive, cumulative, or sustained. Illuminating the virtual environment through direct physical interaction was a concept further explored and refined in Wake.

Takeaways
Sand VR was a productive investigation into the real-time rendering of real-world objects manipulated by co-present, co-located participants within an abstract virtual environment. Manipulating the intuitive, tangible material of kinetic sand was observed to be a pleasurable medium lending itself to a system for collaborative and parallel play within a loosely structured infinite game. The project was influential to the design of Wake in both technical and conceptual ways. Technically, this proved that a computationally intensive depth stream could not only be rendered in real time at a frame rate appropriate for VR, but it could be networked and streamed to two headsets simultaneously. Though the Intel RealSense used in Wake required its own specific computational strategies, what we learned about the Kinect in Sand VR was useful in the approach we took with the RealSense depth stream.

Body, My Body: Improvisational System for Embodied VR

"Body, My Body" is an extended project created in collaboration with *slowdanger* (Anna Thompson and Taylor Knight) involving motion capture, live performance, and facilitated co-presence in virtual reality. The project consisted of a live performance and an improvisational system. The live performance for an audience without headsets involved a virtual environment manipulated in real-time by dancers wearing Vive trackers, and projected

[48] By relying on this physical interaction, Sand VR does privilege an able body in terms of movement of hands and arms, but does not require full body movement.

around the audience. The Embodied VR improvisational system is a participatory experience for one participant in-headset and two dancers, and is most relevant to the Wake experience, as it involves a similar asymmetric, co-located, co-present participant-to-performer relationship.

Body, My Body: Embodied VR

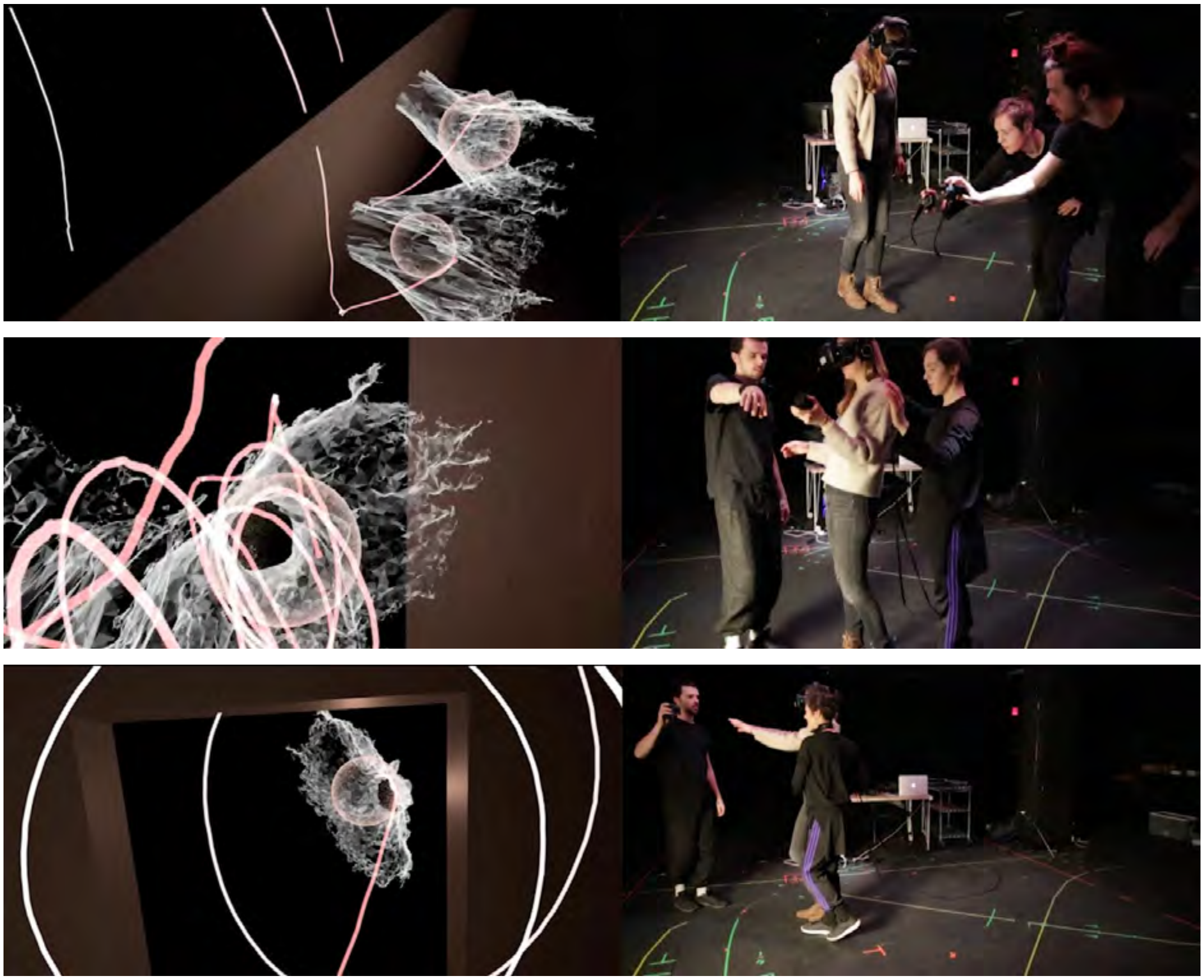
The *Body, My Body: Embodied VR* system explores embodiment, co-presence, and navigation of virtual space through abstraction, movement, touch, and proprioception. This project is a participatory VR experience for one guest and two dancers, whose real-time tracked movements are reflected in the virtual environment using Vive trackers. Though the dancers are not represented realistically, but rendered as abstract avatars, an intimate and synchronous interaction is still possible. The piece centers kinesthetic awareness, improvisation, and mutual navigation through a darkened environment illuminated by tracked movements of the asymmetrically co-present participants.

Experience Flow

This project explored co-located facilitation of a participant in VR, by two people who are not in-headset (i.e. asymmetric, co-located, co-present VR). This concept was further explored and refined in Wake, with the addition of mixed reality through a real-time streamed depth camera feed, and passive haptics with tangible sand.

In the Body, My Body experience, the virtual environment begins in darkness, a response to VR as a physical blindfold to the outside world. Two co-located dancers are represented as abstract avatars with a light in their centers, and a “tail” rendered as a continuous line drawn in virtual space, which fades over time. As the dancers move and interact with the participant, their avatars leave traces of their movement path, and illuminate the virtual architecture of the space, acting as flashlights and pathfinders for the person in headset. The participant is able to move and follow the dancers through witnessing their virtual avatars, and can speak to and be physically guided by the dancers in a mutually negotiated, embodied dialogue. Though the headset is a physical barrier between the co-located participants in this experience, and the virtual avatars do not appear human, an intimate and synchronous interaction is still possible.

This project engages the complex issue of trust within the liminal space between virtual and physical environments, specifically drawing attention to the persistence and implication of the physical world and co-present people within it. The system was not tested with naive participants, however, so the project worked with the assumptions and expectations of the creators and designers, where trust was already established between them. Doing the user study for Wake was very important to examine and question my own biases and those of my collaborators.



Images: Headset view (left), and installation view (right). Dancers interacting with participant in VR.

Takeaways from Body, My Body

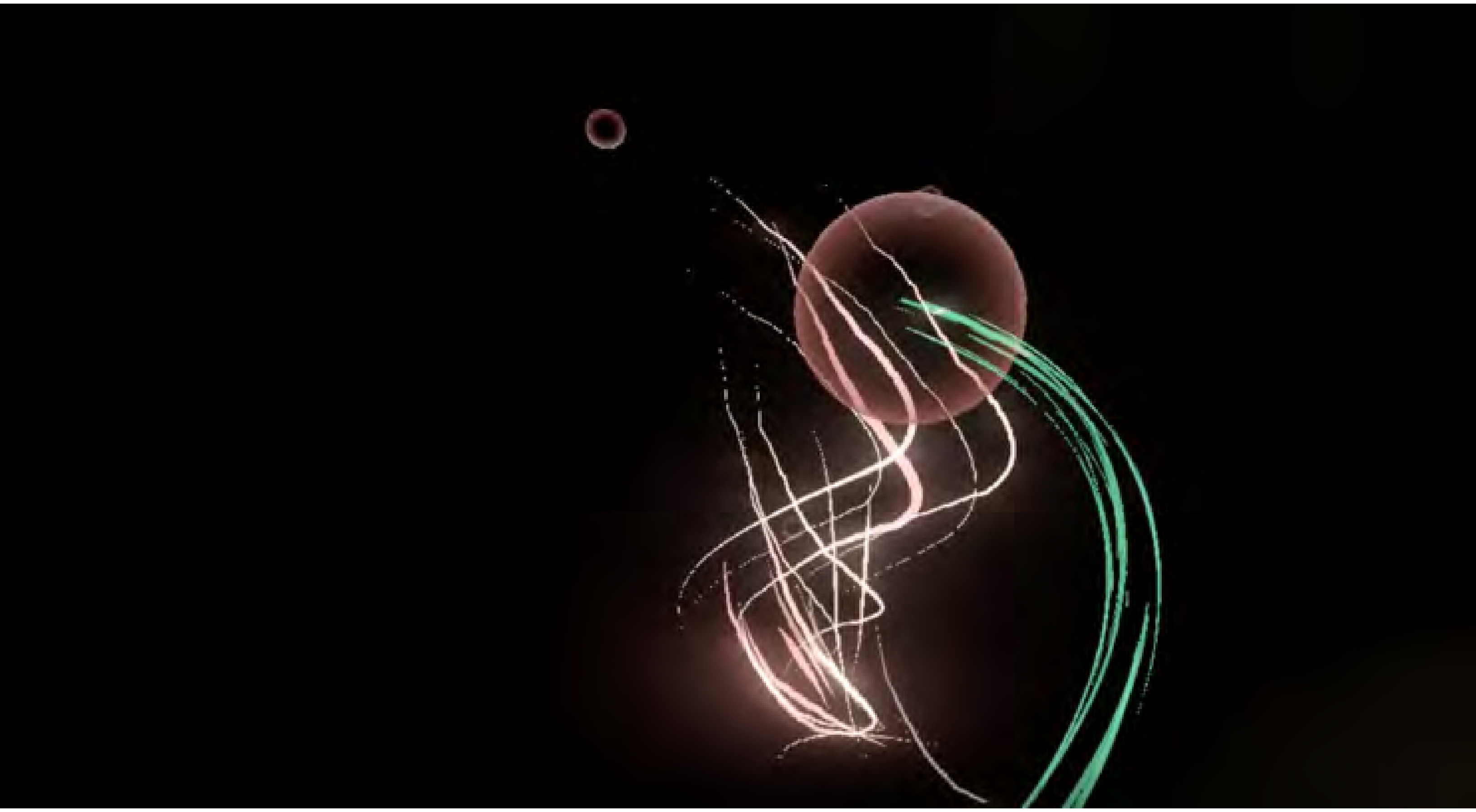
Body, My Body directly influenced the design of Wake in multiple ways. First, the asymmetric performer-to-participant scenario, with two tracked performers and one participant in-headset, was similar (though not the same) to the asymmetric scenario used in Wake. This project also began in darkness and revealed an environment through movement. Wake utilized this strategy as well, though the illumination was cumulative in Wake, and in Body, My Body the lights served as flashlights. This project used a line renderer to track and leave traces of movement using Vive trackers, and this was utilized in Wake by revealing a the participant's tracked path at the end. This project also explored the sense of co-presence rendered visually as abstracted, but felt physically and proprioceptively as real, with co-located dancers. Perhaps most importantly, this project began an inquiry into trust in head-mounted XR experiences that would be explored in-depth in Wake.

2.7 Building on These Influences and Insights

As we will see in the next chapter, my thesis project was directly influenced by the artistic and scientific lineage articulated in this chapter, and built upon the insights and techniques explored in my previous experiments described here. Specifically, in *Sand VR* I used a depth camera to render in real-time an aspect of the physical world, in this case the tangible material of Kinetic sand. *Sand VR* also explored shared experiences through interaction of co-located, co-present participants within a virtual environment. In *Body, My Body,* my collaboration with *slowdanger* was deepened and our research concerns clarified. The concept of physical and verbal facilitation for one participant in-headset, within in a walkable virtual environment, was originated. Primarily, we explored embodiment and proprioceptive sensory awareness in a mediated, hybrid environment. Specifically, we created a system for the improvisational generation of movement pathways (using Vive trackers) to guide a participant through a virtual space. Both projects utilized darkness and illumination triggered through participant interaction as a virtual environment design strategy. These explorations led me to the creation of my thesis project, *Wake*. In the briefest terms, *Wake* is a guided experience in mixed reality for one participant, one facilitator, and one dancer. This shared experience in which both participants are tracked and interact in a virtual environment, but only one person is in-headset, is an example of ACLCPMR, as articulated in the introduction chapter.

In *Wake*, I built on the technical ability to render the physical environment in real-time, this time exploring the social, interpersonal nature of rendering a co-located person using high photographic realism, using the Intel RealSense depth camera. In collaboration with *slowdanger*, we developed a choreographed experience (i.e. a designed participant journey, with a beginning, middle, and end) centered around embodiment and co-presence.

To challenge my own assumptions and bias about these previous projects, as neither *Sand VR* nor *Body, My Body* had been explicitly tested with a larger sample group, I decided to conduct a user study with my next project. Taking a mixed methods approach utilizing qualitative and quantitative data, I developed an experience which studied proxemics, affect, and social psychology within the context of embodied interaction design for my final thesis project, *Wake*. The following chapters illustrate, interrogate, and discuss the *Wake* experience, methodology and findings from the user study, and resulting design implications. First, I will articulate my research questions.



3. Methods

3.1 Research Questions

Recognizing that we have a body and it affects thought;
Recognizing that we have relationships to other people that are articulated by situations and context;

I ask:
1. What are the implications for the design of co-located, co-present XR (CLCPXR)?
2. How can we use these insights to create meaningful, physically and socially mindful CLCPXR experiences?

And, more specifically:
3. How does having-a-body[49] and an understanding of affective and social experiences tell us new things about designing ACLCPMR?

For example, what can we learn through examining first person perspectives with ACLCPMR that inform considerations for:

- experience flow
- intuitive gestures with tracked sensors
- communicative strategies for co-presence
- integrating physical + virtual environment design?

Methodology

3.2 Design Probe

In order to investigate questions of embodied interaction, affect, and co-present relationality in ACLCPMR, I developed a mixed reality design probe and conducted a user study employing qualitative, phenomenological methods as well as quantitative data collection. Developed in collaboration with the multidisciplinary dance and performance duo, *slowdanger* (Anna Thompson and Taylor Knight), I created an asymmetric, co-located, co-present room-scale mixed reality experience for one participant in-headset, with two performed roles: one dancer and one facilitator.[50]

The experience, titled *Wake*, immerses a participant in a virtual environment and uses spoken instructions to aid in navigation of this space, encounters with virtual and tangible objects, and a co-located and virtually present dancer who invites the participant to join in simple collaborative movement. Participants wear a Vive Pro headset, two (Vive) spatial trackers worn at the wrists, and an Intel RealSense depth camera positioned on the front of the headset at the approximate position of the participant's eyes. This is a journey of novelty and discovery, re-orienting perceptions of space and interpersonal communication through embodied interaction.

Following the experience, semi-structured interviews were conducted with each participant, probing questions of the participant's subjective experience, to develop a nuanced understanding of the perceptual and emotional effects of the designed interactions across the participant group.

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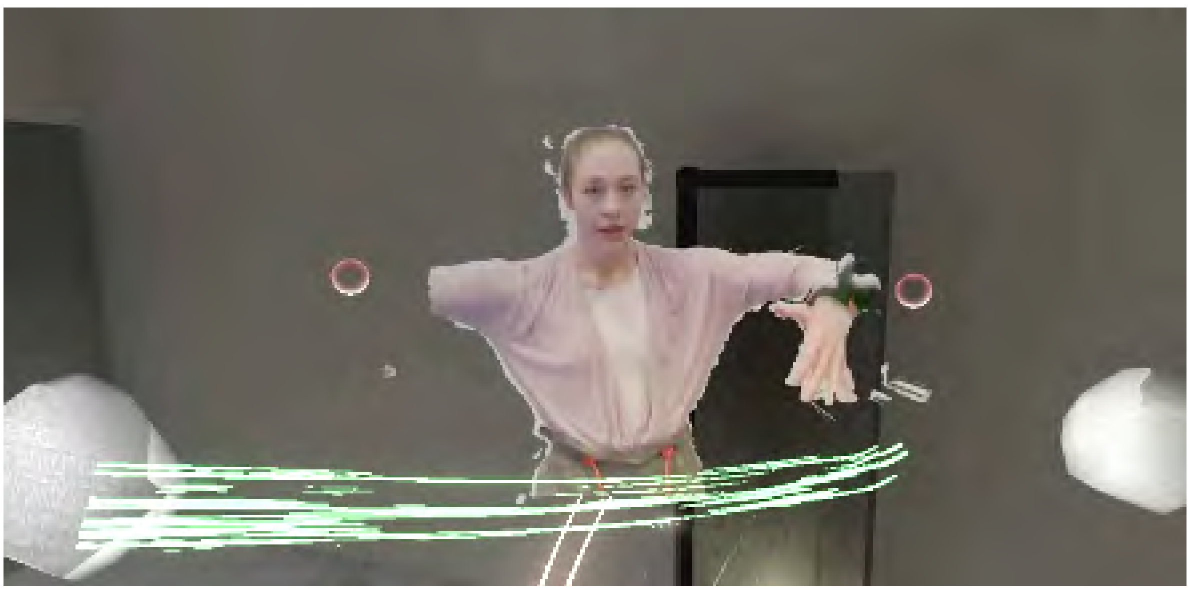
[49] Hyphenation used in conscious reference to Heidegger's "Dasein" or "being-in-the-world."
[50] With additional research and software assistance by Renee Mei and additional programming by Char Stiles



Figures: Wake user study, installed at LikeLike gallery (above) and in-headset recording (below)

In order to investigate questions of embodied interaction and co-presence in mixed reality, I developed a design probe using *Wake*. The study takes the form of a participatory art installation for one headset-wearing participant, who is guided by one dancer, and one facilitator. *Wake* immerses a participant in a virtual environment and uses spoken instructions, audio and visual cues to help the participant navigate this space, and their encounter with a co-located (in the same physical space) and virtually present dancer (rendered in real-time in the headset using the depth camera) who invites the participant to join in simple collaborative movement. Wake creates a scenario for the affective sense of embodiment to be investigated in the context of co-present XR experiences, an area that remains considerably underexplored.[51]

3.2.1 Hypotheses

We hypothesized that our specific methods of spoken and physical facilitation, participant agency, introduction of tangible materials, and real-time representation of a co-located dancer using high photographic realism (i.e. not a virtual agent or human-controlled avatar, but a real-time streaming video) used in our designed experience would engender an exploratory and embodied experience of a mixed reality environment. We hypothesized that participants would self-report emotions which indicated an increasing level of trust over the course of the experience, and were aligned with principles of embodied interaction. We specified this hypothesis further, predicting that participants would engage physically with a dancer using movements and non-verbal communication, moving from the proxemic zone of social space, to the closer zones of personal and intimate space, signifying interpersonal connection and trust.

3.3 Methodology

3.3.1 *Wake* User Study with Phenomenological Methods

The user study (N = 25) consisted of 25 participants with an age range of 21 to 48. Participants were recruited from universities around Pittsburgh, mainly Carnegie Mellon University, and some from professional spheres (1 nurse, 1 filmmaker, 3 museum curators/designers). All participants had a baseline of using mediated technologies for communication. Participants ranged from novice (never used any XR before) to experts (VR Developers). Two standardized metrics were used to identify emotion and interpersonal closeness : the Emotional Wheel and the Inclusion of Self in Other Scale.

Participants engaged in an approximately 10-minute ACLCPMR experience (*Wake*), followed by semi-structured phenomenological interviews (Creswell, 1994; Mason, 1996)[52] probing questions of bodily, cognitive, and emotional experience.

[51] Tham, Jason, et al. "Understanding Virtual Reality: Presence, Embodiment, and Professional Practice." *IEEE Transactions on Professional Communication* 61.2 (2018): 178-195.
[52] Creswell, John W., and J. David Creswell. *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications, 2017.

3.3.2 Semi-Structured Phenomenological Interviews

Participants were asked questions concerning :

1. Bodily Sensations

2. Emotional Experience

3. Relationship to the Dancer / Facilitator

4. Interaction and Spatial Design

Such as:
How does your body feel now right after taking off the headset?
How did the dancer communicate with you during the experience?
How did you communicate with the dancer while wearing the headset?
What was it like when you first saw the dancer?
How did you determine how to navigate the space?

The interviews were structured to capture the ephemeral, embodied sensations / heightened sensory perceptions that occur during the crucial re-negotiation of reality directly following the removal of the headset. This was an attempt to access the intuitive, sensing, feeling *almost-dreamstate* of the participants without bringing them too far into an analytical mindset. After these initial sensations and responses were captured, the questions moved on to more analytical or self-reflective questions.

There was a clear shift in vocal tone with most participants over the course of the interviews, which signified this transition from the “XR dreamstate” to the analytical, conversational perspective. Much of the interview conversations covered the participant’s memory recall of interactions within the experience, their spatial, communicative, and perceptual sensations and experiences, and relationships to the virtual and physical environment, hardware, and co-located dancer and facilitator. These were related to emotional experience, social interaction, and sense of connection to their own bodies and that of the co-present dancer.

3.3.3 Data Collection

The user study used mixed methods of data collection, both qualitative and quantitative.

Standardized Metrics

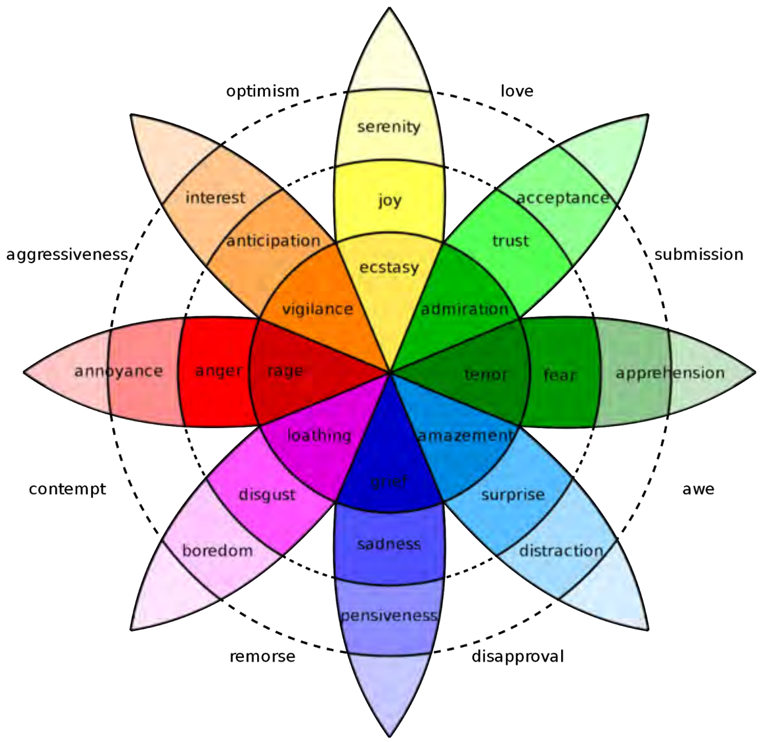
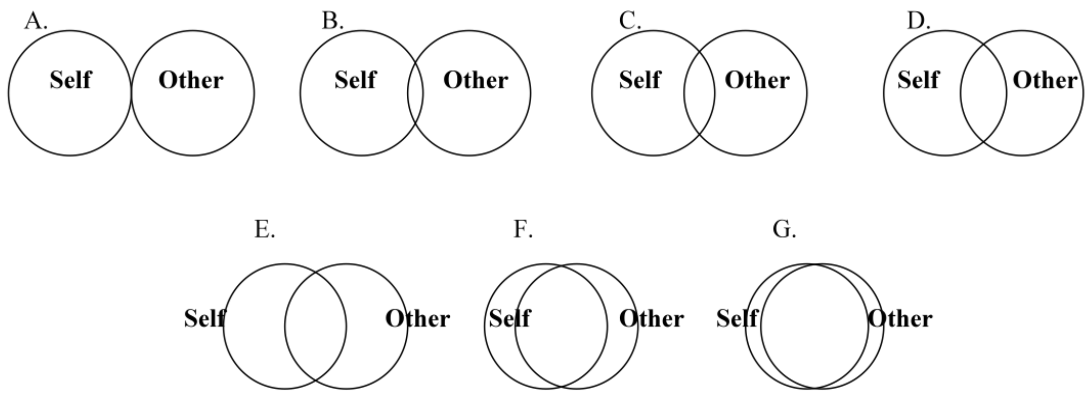


Image: *Wheel of Emotions*, Robert Plutchick, 1980

Psychologist Robert Plutchick developed a theory of 8 primary emotions, illustrated on this wheel in the middle ring (i.e. joy, sadness, anger, fear, trust, disgust, surprise, anticipation) and their related emotions. Each emotion is shown with its inverse directly opposite, and each segment shows related emotions in differing levels of intensity. This representation of emotions was useful to my study to provide a standardized method for participants to self-report what they felt during the ACLCPMR experience. Participants were asked to choose five emotions they felt during *Wake*, and then discussed with the PI the specific moments they felt these emotions. In combination with the longer interview questions, the Wheel of Emotions helped to focus the conversations and revealed common themes across all participants. A key finding was that all 25 participants identified trust as part of the *Wake* experience. This will be discussed more in depth in the Findings and Outcomes chapter.



Inclusion of Self in Other Scale

The Inclusion of Self in Other Scale[53] was developed by psychologists Aaron, Aaron, and Smollan in 1992, to measure interpersonal closeness. This metric was used in the *Wake* user study to investigate the relationship of the participant to both the dancer and facilitator. Participants were asked to choose the illustration that best represented their relationship to each, and if they felt their relationship changed or evolved over time, they were able to choose more than one illustration. They then described their choices, identifying when in *Wake* each type of relationship was experienced. This metric was chosen for the user study to help clarify the sense of connectedness or emotional bond that participants were able to establish with the two different performing roles, to help understand the effects of technological mediation on interpersonal connection, and the differing ways the dancer and facilitator role functioned in the experience. The findings from this scale will be articulated in chapter 4.

[53] Aron, A., Aron E. N., & Smollan, D. (1992). Inclusion of other in the self scale and the structure of interpersonal closeness. *Journal of Personality and Social Psychology, 63*, 596-612.

3.4 Participant Journey

3.4.1 Wake Journey Map

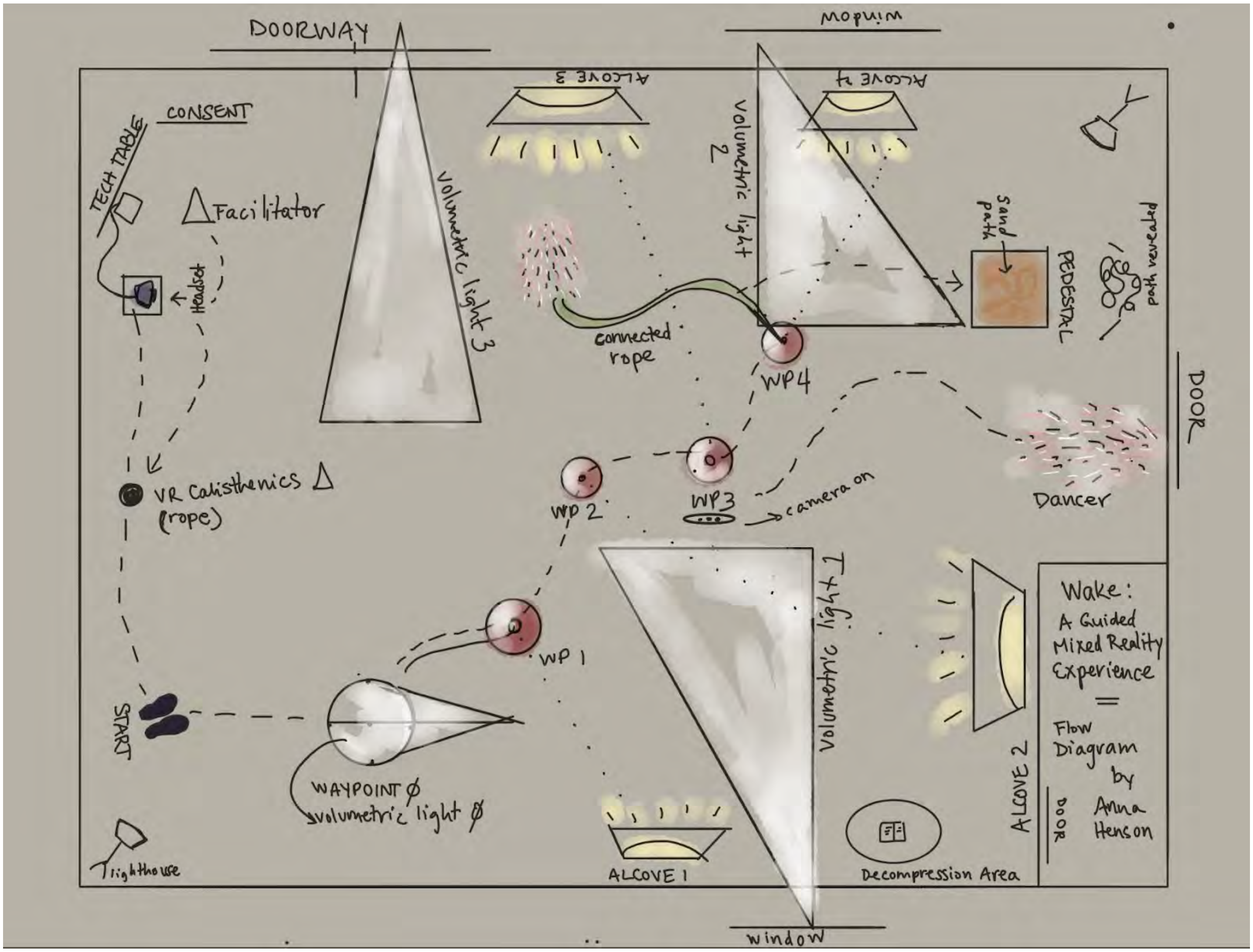


Figure x. *Wake* Journey Map

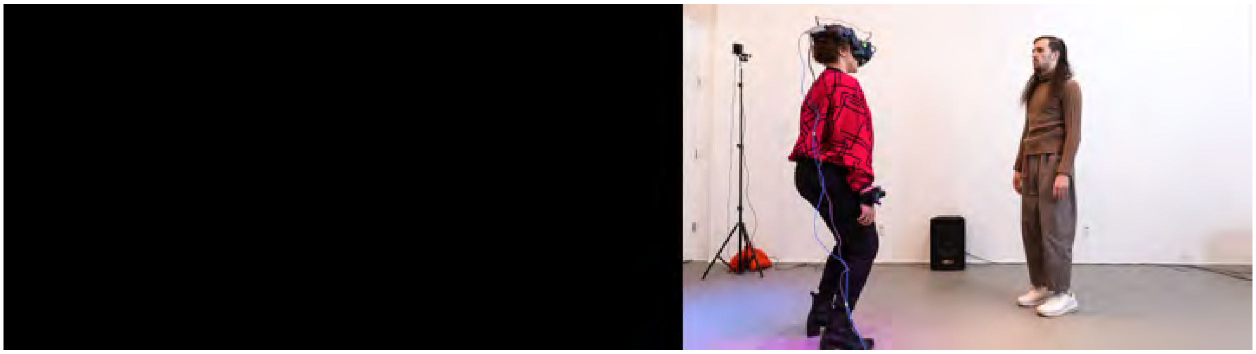
3.4.2 Explanation of Journey Events

Images

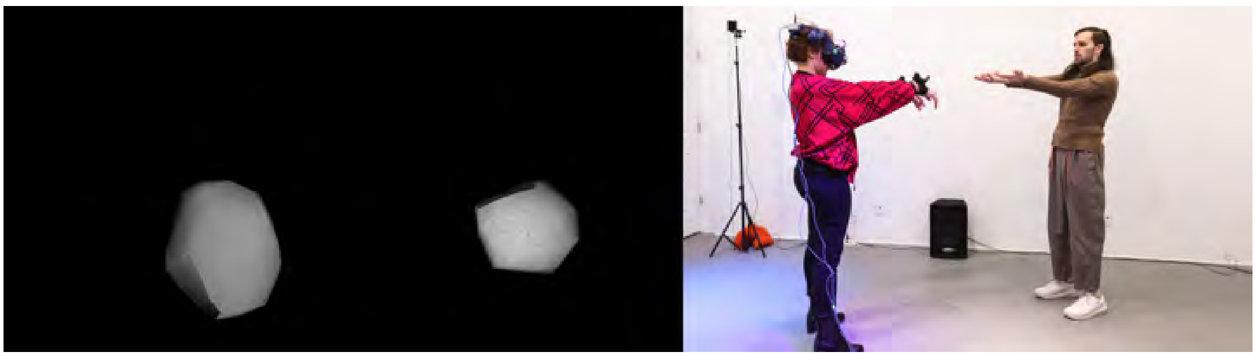
IN-HEADSET VIEW **PHYSICAL SPACE**

A. Start : Headset On, Darkness in Headset

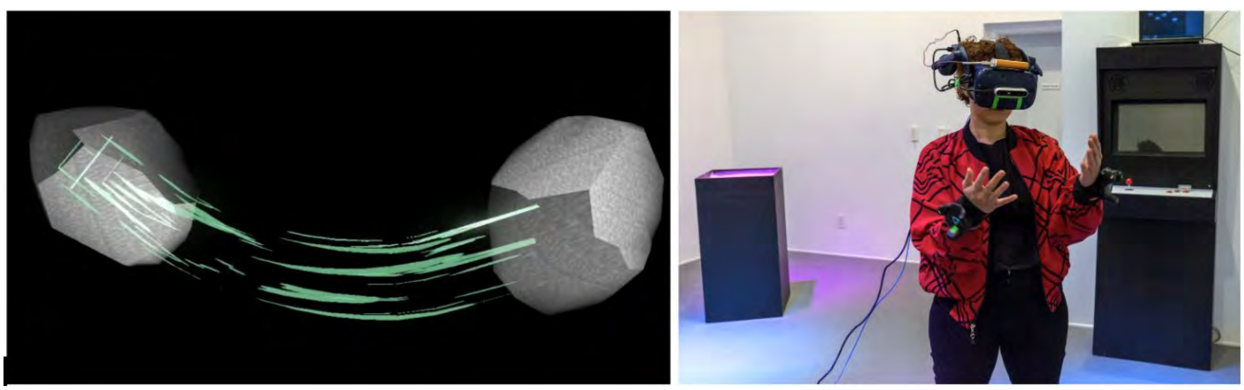
B. Physical Orientation Exercises (walking perimeter of space)



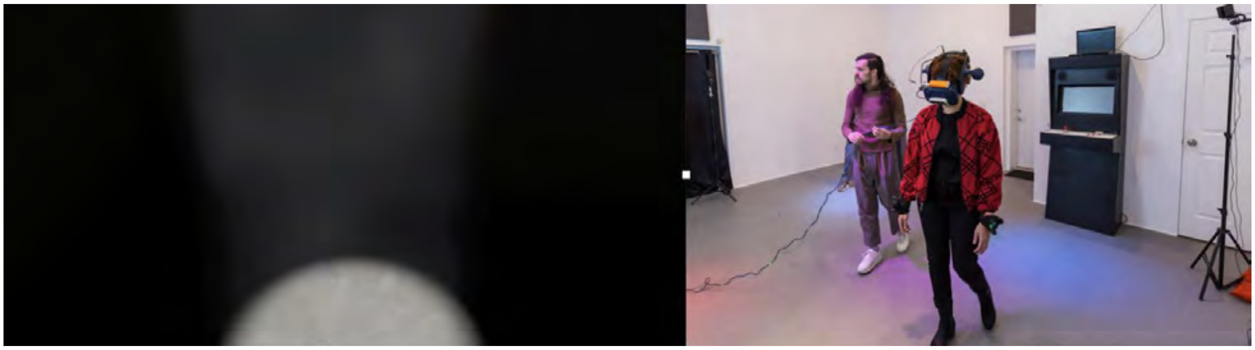
B cont. Physical Orientation Exercises (guided breathing, simple movements)



C. Virtual Orientation Exercises (white rocks appear at position of wrist trackers)



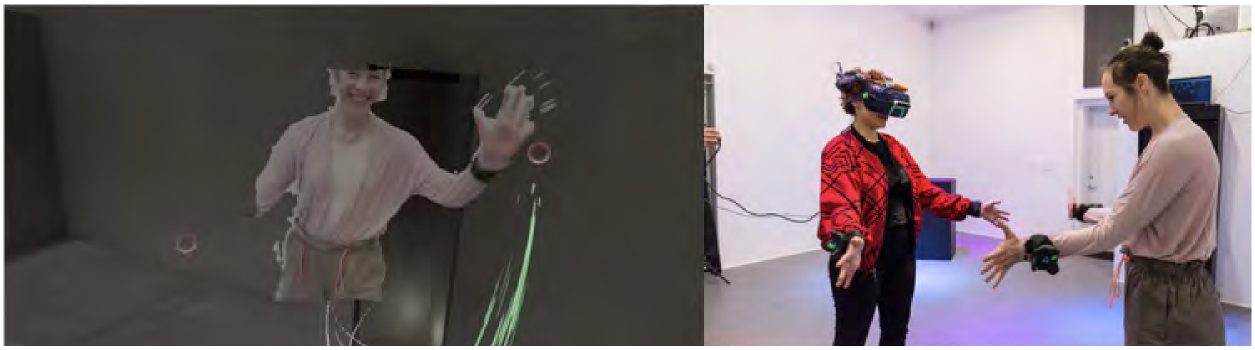
C cont. Virtual Orientation Exercises (green rope tethered between two wrists)



D. Step Into The Light

F-G. Virtual Sphere Interaction (x2)

H. Green Rope Tethered to Dancer (Glowing Particle)



I-J. Participant Sees Dancer in Camera and Moves Together

K. Participant Connects to Dancer Through Touch

L. Participant Draws Their Path in Sand

M. Player Explores Their Path

3.5 Wake Design Narrative

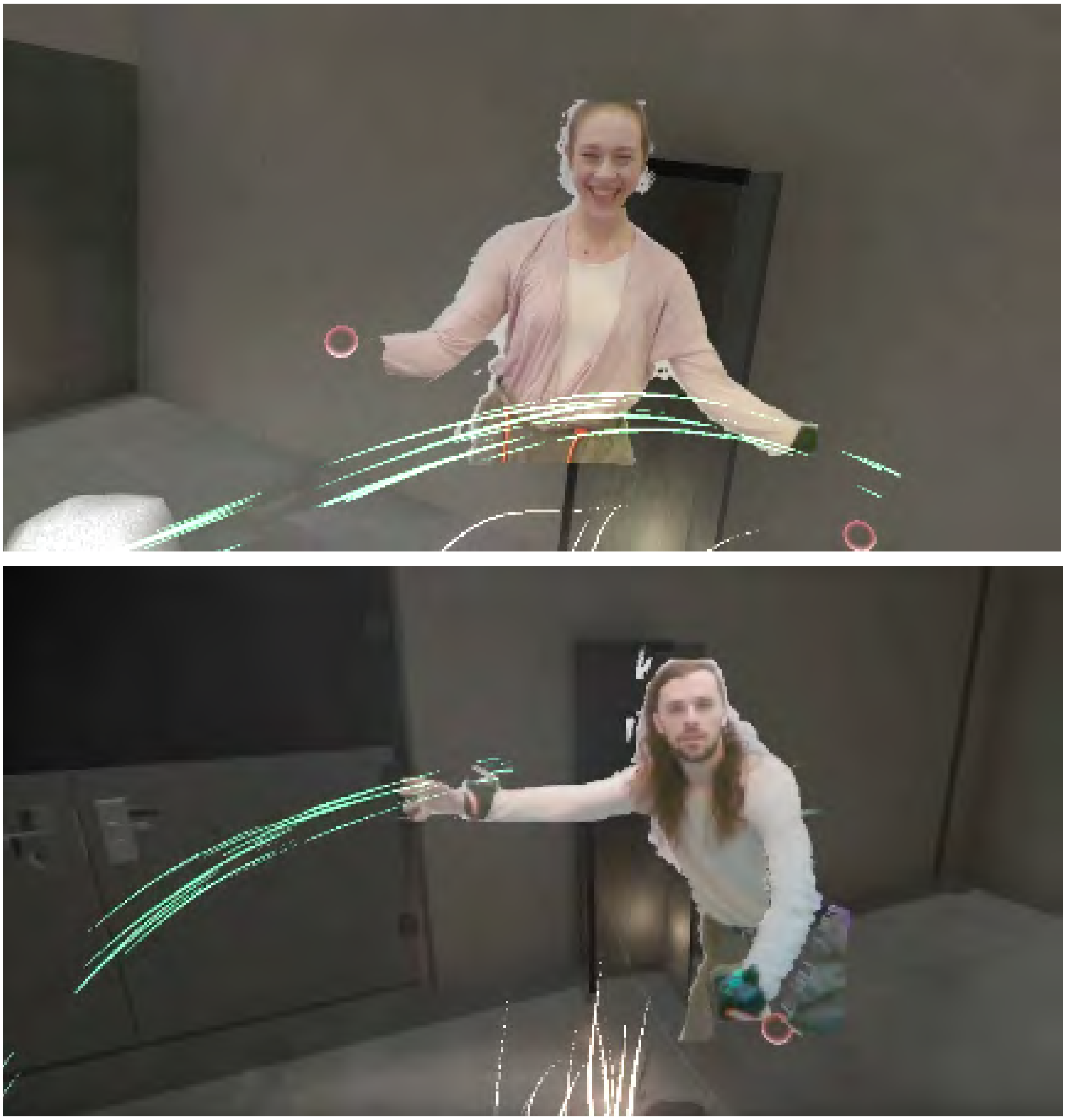
3.5.1 Representing the Dancer and Participant

Figures: Participant interacts with dancer, wearing HTC Vive Pro with Intel RealSense camera mounted on the front, allowing a real time streamed depth video of the dancer to be seen.

Intel RealSense Camera

In this project, I wanted to explore the effects of a co-located dancer streamed in real-time to a headset, represented as realistically as possible. This would allow for improvisation between the dancer and participant, and communication through physical movement and facial expressions, as well as the possibility for spoken communication and touch in combination with the visually mediated representation of the dancer in the virtual environment. In order to visualize the dancer in real time, I developed a method for rendering the color and depth feeds from the Intel RealSense camera in Unity, which streamed to the VR headset, allowing the participant to see and respond to the co-located dancer. This will be examined further in the technical discussion in section 3.7.

Figure: Intel RealSense D415 Depth Camera



Figures: Dancer role as visualized in participant headset, interacting with virtual objects in virtual environment. Dancers: *slowdanger*, Anna Thompson (top image) and Taylor Knight (bottom image).

3.5.2 Spatial and Environment Design

The virtual environment became a literal representation of the real space, using an accurate to scale 3D model of the gallery in which the user study was conducted. A few interesting insights ensued from this change, such as participants thinking they were seeing through the headset to the real room in front of them, akin to AR in VR, and others reporting that they felt comforted by the similarity of the virtual space to the physical space, and they felt that they understood the size and their position in the virtual space better because it reflected the physical room, and therefore they were more comfortable moving freely within this space while wearing the headset.

Due to the depth filtering method we used with the Intel RealSense camera feed, the physical space could potentially be partially seen if the viewer looked up to the ceiling, or moved within a certain distance to a wall or furniture. The physical room was cleared of objects which could be tripping hazards, and the choreography of the movements and interactions were facilitated by the two performers to allow for the most unrestricted movement, however some participants did occasionally see the real environment in the camera feed.

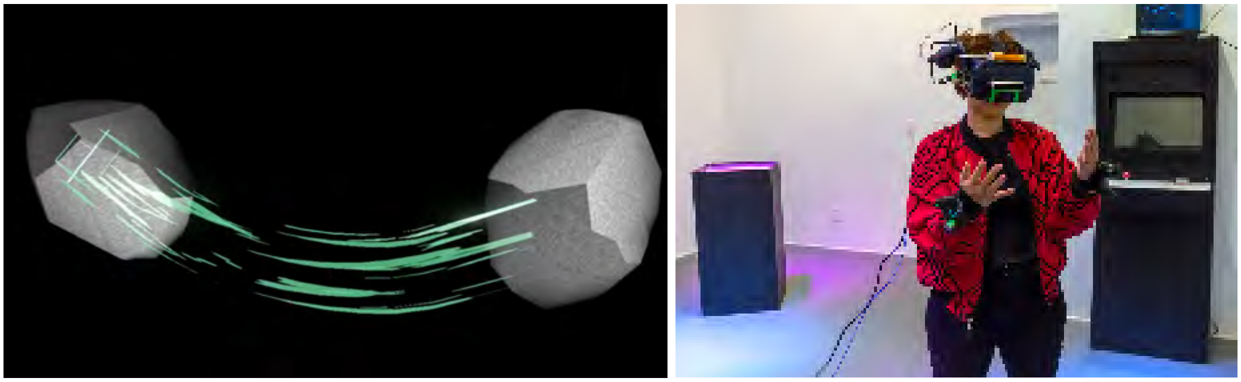
The gallery space had several physical structures in it which were used as positions for virtual objects in the headset. The rectangular structures used in the second prototype were reused in the third prototype. The environment in this prototype began in complete darkness, and was illuminated as the participant navigated through the virtual space. Participants encountered virtual objects (red spheres) which triggered small yellow spheres to be released from them. These became lights that illuminated the rectangular virtual objects and surrounding space in the environment. This action began to illuminate the virtual space, allowing the participants to see that the room they were in reflected the physical space in which the experience was taking place. Not all participants immediately recognize this however but the sense of seeing the space was still found to be effective in helping the participants feel comfortable moving within it.

Figures: LikeLike Gallery, with Wake sandbox pedestal on left, and pre-existing physical structure on the right. (right) Scale 3D model of LikeLike Gallery used in the Wake experience (Courtesy Paolo Pedercini).

3.5.3 Interaction Design

Facilitating Embodiment Through Interaction: Teaching Participants the Tools of Their Environment

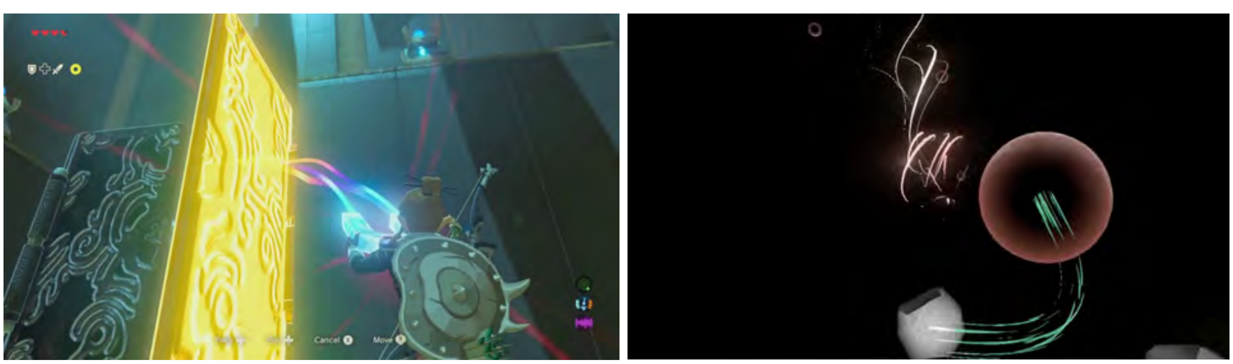
In the beginning of the experience, a participant sees darkness in the headset, and engages in Physical Orientation Exercises as guided by the facilitator. These consist of breathing exercises, walking around the space, and mild physical movements used to encourage a freedom of movement later in the experience. Virtual objects begin to appear seamlessly while this is happening, which aims to provide a smooth transition into the virtual world during the period of adjustment to the physical hardware. With this gradual adjustment to the physical and cognitive scenario involved in the mixed reality experience, a participant’s embodiment cultivated. First, the objects shown are two white rocks, which are tracked to the Vive trackers worn on the wrists. After these objects are adjusted to, through exploration with wrist and arm movement, a green rope appears between them, which the participant is encouraged to explore, to discover physics.



Figures: In-headset view (left): Two rock-like objects represent tracked wrists of participant, and green physics rope is demonstrated and explored by the participant. Participant (right) explores virtual objects, wearing Vive trackers.

A challenge in virtual reality interaction design is the construction of meaningful gestures through intuitive physical interactions. While this topic has been explored by other practitioners, especially in relationship to gaming, the process in *Wake* was more like guiding a blindfolded person through a physical space, and encouraging the participant to engage in "natural" dynamic movement along specific waypoints in VR. Some issues we encountered were the lack of peripheral vision in VR, the headset restricting movement, the waypoints originally starting on the floor and though iterations we moved them to mid height so that the participant could ideally look straight ahead rather than downwards. Through an iterative design process, we gained embodied knowledge leveraged by the final *Wake* experience.

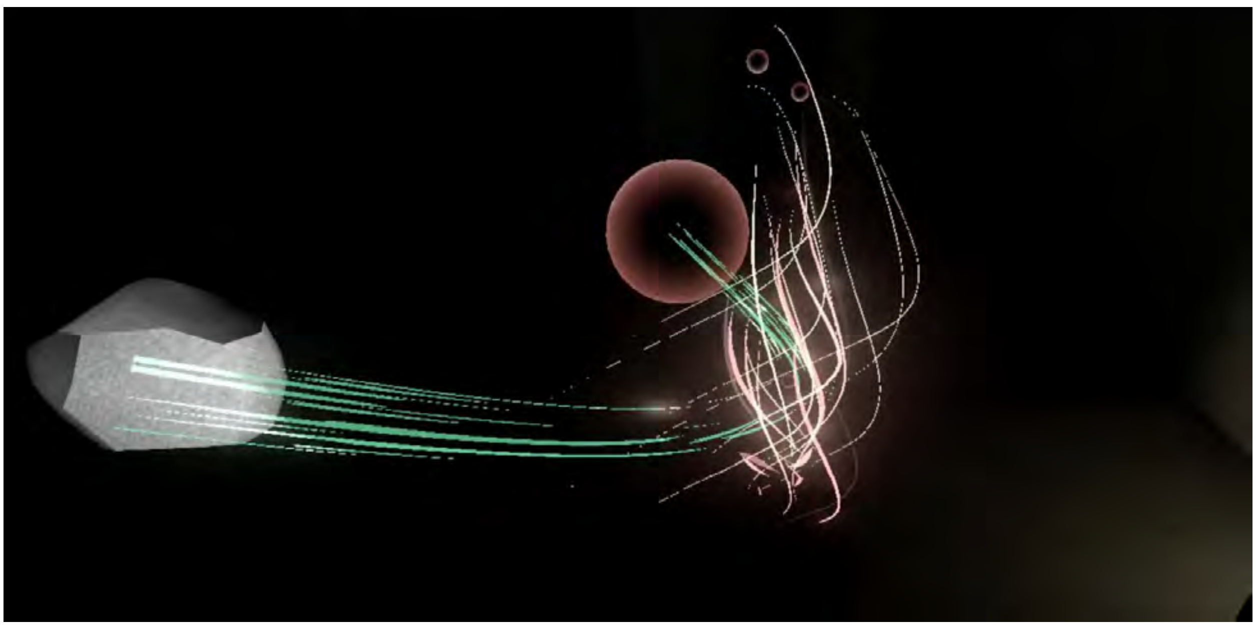
An example of an embodied interaction design discovery was the way we designed a flexible, yet specific pathway for the participant to move through. We were inspired by the magnetic rope in Zelda, for the way that it used dynamic physics and also attached to a certain point, which the character moved towards. We thought this strategy might work well for our experience, to help participants move through pre-determined waypoints (visualizes as red spheres), but in a dynamic, natural way.



Figures: (left)The Legend of Zelda - Breath of the Wild - Ka'o Makagh Shrine, Image Credit: https://www.youtube.com/watch?v=Ka-d8MVTxv4, (Right) *Wake* Green Physics rope with participant tracked wrist (white rock), attaching to next red waypoint sphere, showing path which moves dynamically with participant towards next goal.

As the participant arrived at the red sphere, and reached into it with their hand (and wrist tracker collision was activated) they would trigger a light which would glow inside the sphere and then shoot outwards to illuminate a part of the virtual environment. Similarly to Body, My Body, in *Wake*, light and darkness are used as attention focusing tool, and repeated interactions which trigger illuminations convey ownership of or immersion in the virtual environment. The red spheres were interacted with three times by a participant, encouraging mastery over this mechanic.

An interesting observation gathered from the phenomenological interviews regarding touch and synaesthesia was the sensation of warmth when the red spheres were encountered. Some participants reported that they physically felt warmth, others reported that they desired to feel warmth, or felt they "should" encounter this sensation due to haptic expectations, triggered by the appearance of a glowing light in conjunction with the physical act of reaching towards this light. Tracking was achieved through Vive trackers, but we did not have full hand or finger tracking, which woul dhave increased the precision of the collisions, and potentially helped the haptic/synaesthetic sensations occur more naturally.



As participants interacted with the spheres, this triggered a glowing smaller sphere within the red sphere, which sequentially triggered small lights in the virtual space, illuminating the virtual environment. By revealing a virtual environment through direct, embodied interaction by the participants, it was hypothesized that the participants would feel more ownership over the space, and would cultivate a continued sense of interest.

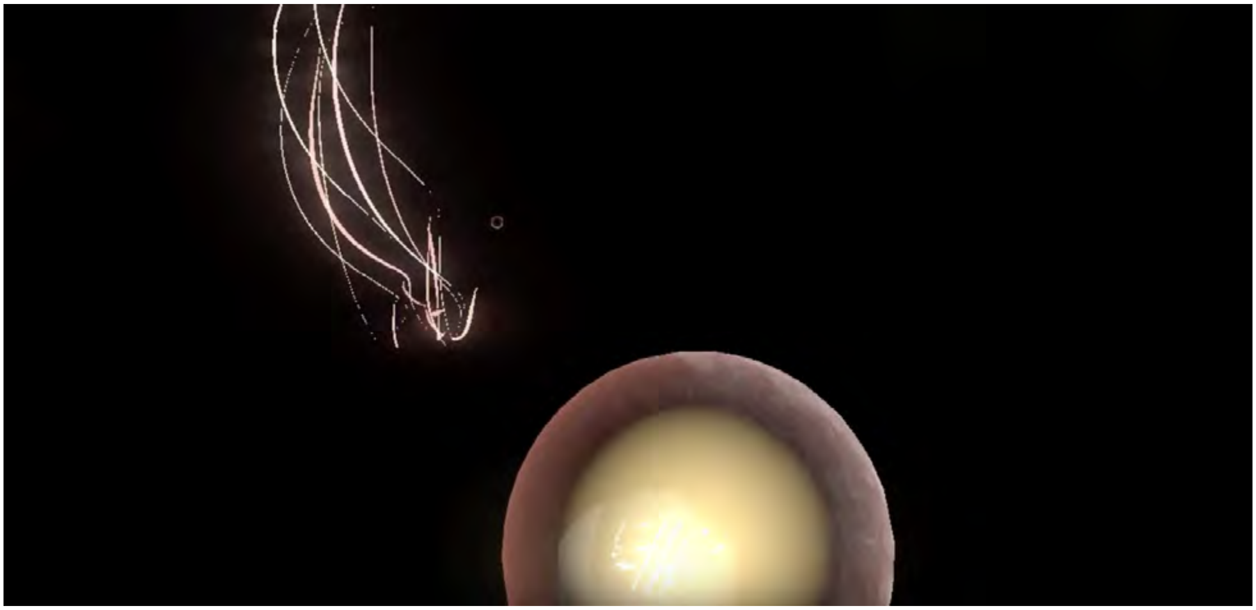


Figure: In-headset view. Glowing light is triggered by participant when they reach into red sphere.

Figure: In-headset view of virtual room after participants have triggered all lights, illuminating the space.

3.5.4 Sound and Facilitation

During the prototyping process for *Wake* we used both spoken instructions and pre-recorded instructions. The pre-recorded instructions were determined to be too “authoritarian” feeling, and also were not as flexible or responsive as live spoken dialogue between the facilitator, dancer, and participant. In the final iteration, the dancer and facilitator spoke to the participant in an un-mediated way - i.e. directly to them. Regarding the voice in new media, theorist Frances Dyson explains, "[t]he familiarity of the voice blunts the sharp edges of telepresent culture, dampening the potential viability of troubling questions concerning the self, existence, the real, and the social. Sound disappears into the voice the same way that the voice encloses and hides the technological means of transmission and reproduction."[54]

Wake utilized an ambient soundtrack created by slowdanger to set the mood of the experience, and also to fill in space, attending to part of brain that could be distracted by silence. The music was subtle, and some participants, when asked, couldn't remember it at all. In this way, the music did its job to help focus attention on other embodied sensations and perceptions.

We wanted to get away from the authoritarian aspect of the pre-recorded audio and have the dancers be able to respond in real time. From early testing, some participants responded that the robotic sound was uncomfortable or "authoritarian," so in order to build up the trust during the experience, we choose to use real sound after we made that choice about "authoritarian" voice - and it kept the experience more flexible because it was real time.

However, if we had had a microphone (which was discussed) where the dancer could speak to them in real-time, in other words giving them the ability to augment their voice in real time, this would have been very interesting to have had the sound / spoken spectrum from augmented to real and interview participants on their experience of that in terms of its embodied interaction / trust / emotion.

3.5.5 Haptics and Shared Tangible Objects

Passive Haptics: Sandbox

In the third prototype, we changed the shared tangible object to sand, instead of Play-Doh. I used sand for the aptly titled Sand VR and had found it a successful material. We used Play-Doh in the previous two prototypes and decided to change the material to sand so we could have a larger amount, creating a more "environmental" tangible material to interact with. Japanese Zen gardens and children's play therapy sand tables were influential in creating the sandbox. We used Kinetic sand at the beginning, pre-headset, as a sort of sensory priming material, a place to draw the participant's focus to a tangible interaction, and to begin the relationship with the participant to the facilitator without any technology involved at first. We created a second sandbox to be interacted with while wearing the headset, and we used regular play sand instead of Kinetic sand here. By having these two tangible interactions without and with the headset, we were curious about how the two would relate to or inform each other. We wanted
to build a sense of familiarity, maintain a connection to physical environment, and create a boundary object or transitional object.

[54] Dyson, Frances. *Sounding new media: Immersion and embodiment in the arts and culture*. Univ of California Press, 2009. p. 9.

Figures: Participant draws path in the sand with dancer (top), in-headset view of sandbox (bottom).

3.5.6 Traces of Movement : Tracked Participant Path

Participants' path through space was tracked throughout the experience, using the Vive trackers worn on their wrists. Near the end of the experience, the tracked path was revealed in the space, rendered as a white line which tracked the movements of the participants. They could then walk through their path, as a memory or trace of their experience rendered physically. This was created in order to help visualize and enhance the embodiment of their actions, as occurring across physical and virtual space, and across time. For example, in the bottom left image, shown below, the participant can view, and walk around, their circular movements which rendered this circular path revealed to them at the end of the experience.

Figures: Participant path rendered in virtual environment (left), Participant explores the path in space, and cables managed by facilitator (right).

3.6 Wake: Social and Collaborative Perspectives

3.6.1 Collaboration, Choreography, and Improvisation: A Dialogue With *slowdanger*

Figure: slowdanger, Anna Thompson and Taylor Knight, Image credit: Audrey Gatewood

Bringing original, complex projects to life which necessitate resources and skill sets beyond those of one individual, requires communication, translation, and dedication among collaborators. My work is technical, aesthetic, performative, and situated in real-time interactive experiences. Each project is created by an explicitly designed and necessarily flexible network of human-to-machine and human-to-human collaborative scenarios. Therefore, collaboration across disciplines is essential to my work. Projects emerge through an evolving dialogue between both human and machine elements in which emerging problems are identified, structured, and solved, often in ways that could not have been anticipated from the outset.

The ability to perceive and respond to the changing needs of a collaborative system is a skill that can be honed, and one that I have refined through my career working in teams, as a theatre designer, technical and creative director, experience designer, and producer. My research and practice find new ways for developing technologies to co-evolve[55] with human needs for communication, shared experiences, sensory integration, and storytelling. Technology serves the communicative and experiential needs of the project. And when those needs require technologies that do not exist, then they must be developed and tested in tandem with the experience as a whole.

[55] As Paul Dourish and others make clear, this "co-evolution" of technologies with human life is inevitable, and therefore all the more important to design technologies which help us to thrive.

The user study served as an opportunity to test the results of a new technological system implemented within a performative and exploratory scenario for participants. Through interviewing and observing participants, my collaborators and I were able to test our assumptions about the effects of our mixed reality experience.

For me, technology exists as an augmentation or tool of human expression. Projection design for performance adds a mediated layer of content enmeshed with live performers and physical environments, situated within a relationship to an audience (whether immersive or separated by a "fourth wall"[56]). Head-mounted XR provides an extension of the concepts involved in projection design by allowing for immersion within a responsive environment in which mediated layers of content are directly influenced by interactions from participant[s].[57]

Identifying the right collaborators is crucial for work at the intersections of disciplines to be successful. The multidisciplinary performance duo, slowdanger (Anna Thompson and Taylor Knight) and I began our collaboration in 2016. Given my background working with performers, my investigations into technology at Carnegie Mellon were rooted in a desire to create performative experiences, through direct capture and representation of expressive human bodies (i.e. a new kind of photography/cinema/theatre), and the construction and choreography of shared, embodied rituals. Regarding dance and embodiment, Slowdanger has extensive experience creating original and improvised contemporary and postmodern dance frameworks, as well as training and teaching philosophy in Laban Movement Analysis, and what they describe as "physiological centering," drawing from somatic practices such as Body Mind Centering[58] and Gaga.[59] Additionally, they create music and sound scores using found material, electronic media, and their own voices.

When I first approached them, I was interested in working with motion capture and dance, and they were fitting collaborators. Over the course of two years, our work together evolved significantly to develop and explore a research question positioned within a dialogue about embodied experience, bodily representation, and interactivity within a human-machine system. Eventually we narrowed this inquiry to focus on immersive, head-mounted XR, working primarily with room-scale virtual and mixed reality and spatial trackers worn on the body.

As our collaboration evolved, we discussed the nature of embodiment, sensory perception, and trust between individuals engaged in physical movement practices. I saw a connection between slowdanger's philosophy and creative / educational practices and the questions I was exploring within real-time graphics, performance capture (i.e. motion and volumetric capture) and head-mounted immersive experiences. I sought to explore how these technical investigations could contribute to aesthetic and psychological inquiries into human experience.

In my collaboration with slowdanger, we open up and enter each other's communities, slowdanger to my Carnegie Mellon community, and me to slowdanger's performance community. I participated in slowdanger's Physical Integration classes to investigate my own embodied experience and learn from their expertise. A critical part of attempting to create embodied experiences with and through technology is to drop my pre-conceived notions of what "embodiment" is, and to cultivate "listening" and "awareness" through first-person experiences, as guided by the expertise of slowdanger.

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[56] The "fourth wall" is a theatrical convention in which an imagined or invisible boundary separates performers from the audience, which the performers do not acknowledge, but which allows the audience to "see into" the world inhabited by the performers on stage.

[57] The term "participants" is more appropriate than "audience" here because the XR experiences I create are experienced through direct interaction, not passive consumption as in a traditional theatre setting.

[58] https://www.bodymindcentering.com/, Accessed December 17, 2018

[59] http://gagapeople.com/english/, Accessed December 17, 2018

3.6.2 Slowdanger's Words:

<u>The Interstitial Space Between Us All</u>

"[This is] a practice of the participant, dancer, and facilitator all submitting into the experience themselves, allowing the experience to be shaped by the interstitial space between us all. There's not one guide. The participant isn't the one guide, the facilitator isn't the one guide, the dancer isn't the one guide. The guide is being built through the process of interacting with each other."

-Anna Thompson, *slowdanger*

<u>Dancing the Technology & Sharing Virtual Space</u>

"The particle system is my costume, or my fabric that I'm inside of that I move and stretch, and it's not about me - they may not even know it's a person - they may think it's a simulation - so then when the camera reveals me, it's more vulnerable because now they can see me in my visible form. It becomes less about me moving to draw their attention to the particle system and more about making them feel like I'm right there with them."

- Taylor Knight, *slowdanger*

<u>Choreography and Improvisation</u>

"[This work is] performative in a way, but it's not about it being performative, and I don't really even consider it a "dance piece" anymore - it's not about technique, it's not about virtuosity, it's not about clever choreography, it's about empathy and sympathy between me and the person that I'm with, and almost trying to put myself in their position and their body.

It takes all my dance training and technique, like tracking bodies in space, and makes this a foundation for me to support them because they're in a disoriented place."

"The choreography in this piece is the physical orientation exercises and the set elements of the experience, like the spheres and the sand. The improvisation has everything to with responding to the participant, in either the dancer or facilitator role."

- Taylor Knight, *slowdanger*

3.6.3 Our Collaboration:
The Importance of Cross-Disciplinary Dialogue in Technology Development

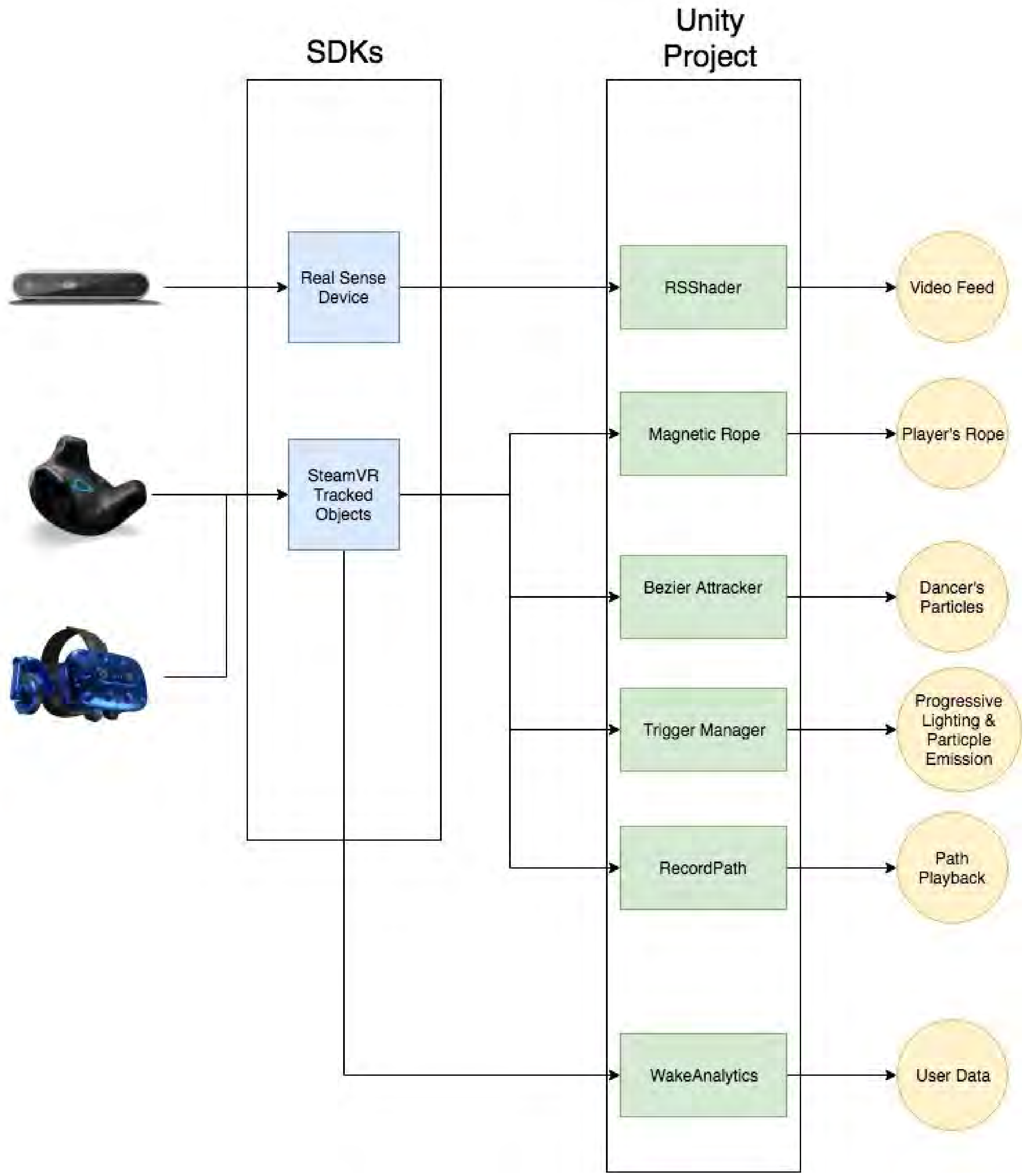
The catalyst for the project was to create an experience that could be used as a tool to examine the ontology of XR experiences. We began with questions, some concerning the physical situation of the hardware as worn by a participant, some regarding common feelings of disorientation in VR, and others concerning the nature of social experience in which another person was both co-located and co-present. We approached these questions from different perspectives: my background as a designer and technologist, and slowdanger's experience as dancers and movement researchers. We found common ground in the ways we understood the human role in the intersection of art and technology and encouraged an expanded dialogue which pushed the boundaries of each of our disciplines. We developed a central research concern examining embodiment within immersive head-mounted media (i.e. "XR"). We see XR, and specifically the blurred physical/digital boundaries of MR, as a human-machine interface which fundamentally implicates the perceptual and kinesthetic nature of the body and its attendant affective responses.

My interdisciplinary practice is a constant dialogue between rigorous computational processes and collaborations with practitioners whose knowledge base is critical to, yet often lacking in technology research and development. My long-term collaborative engagement with movement and dance practices has served as a crucial inquiry into the design of embodied interactions with immersive media. Regarding the closed doors of technology development, I particularly value Haraway's argument for a revised view of what comprises "objectivity" and "truth," in science. Haraway empowers the subjective, first-person perspectives and experiences of those who are traditionally shut out from the rooms and societies in which science and scientific truths are determined and conveyed. Those she calls, "the embodied others, who are not allowed not to have a body."[60] My collaboration with slowdanger and the resulting data and insights gathered here, are exemplar of knowledge creation which could only happen through this interdisciplinary collaboration - and, as I have discussed in this thesis, is largely missing from the dialogue concerning the development of XR technologies.

[60] Haraway, Donna. "Situated knowledges: The science question in feminism and the privilege of partial perspective." *Feminist studies* 14.3 (1988): 575-599.

3.7 Technical Discussion

Wake Systems Diagram



Resources

The project is developed in Unity 2018.2.1f1, and uses the following SDKs and commercial assets:

- Intel RealSense SDK2.0[61] : Depth camera SDK
- OpenVR[62] : Support for VR systems (such as HTC Vive) in Unity
- Hx Volumetric Lighting[63] : Volumetric Lighting package, chosen because it supported single-pass rendering to maintain high frame rate for VR
- iTween[64] : Animation package to automate repetitive animation scripting
- Realistic Effects Pack 4[65] : Particle Effects shader for our physics rope
- Obi Rope[66] : Rope simulation for Unity

The following commercial asset is used to assist the development process:

- QHierachy[67]

The project also makes use of the following open-source assets:

- ShaderForge[68]

Project Technical Overview

The core mechanism of this project utilizes the Intel RealSense SDK 2.0 Unity Wrapper which provides depth camera stream and RGB camera stream as textures in Unity. The two textures are bound to a shader which then utilizes depth culling to define the outline of the dancer and cull the background. The shader is applied to a plane that has dimensions and vertex count aligned with dimensions and pixel count of the streaming texture. The shader also uses per-pixel depth data to displace vertices to re-size the streaming texture to match its size in the real world and also counteract lens distortion in VR.

Along with the core mechanism, we developed a series of game mechanics that serve the purpose of the study and our design. To help a participant get comfortable in the VR environment, we developed a series of Virtual Orientation Exercises[69] physics rope that user can play with in VR before the experience begins. In the experience,

[61] https://github.com/IntelRealSense/librealsense, accessed November 1, 2018.
[62] https://github.com/ValveSoftware/openvr, accessed October 26, 2018.
[63] http://hitboxteam.com/HxVolumetricLighting/, accessed October 26, 2018.
[64] https://assetstore.unity.com/packages/tools/animation/itween-84, accessed October 13, 2018.
[65] https://assetstore.unity.com/packages/vfx/particles/spells/realistic-effects-pack-4-85675, accessed October 2, 2018.
[66] https://assetstore.unity.com/packages/tools/physics/obi-rope-55579, accessed November 1, 2018.
[67] https://assetstore.unity.com/packages/tools/utilities/qhierarchy-28577, accessed October 15, 2018.
[68] http://acegikmo.com/shaderforge/, accessed October 15, 2018.
[69] See Section 5.5.3 on Virtual and Physical Orientation Exercises

players will go through a series of waypoints that are composed of a series of triggers that would trigger particle emission and object animations. Before the camera feed is activated in the game engine, the player will see a programmed particle system with particle path determined by the tracked movements of the dancer (from the Vive trackers worn on the wrists). At the end of the experience, the player will have the chance to explore their path as it is visualized in the virtual environment through a line renderer retrieving the player's recorded path.

To reach the aesthetic goal, we utilized volumetric lighting from Hx Volumetric Lighting and used mixed-lighting on the scene.

Explanation of Key Parts

RSShader

The shader is developed to be able to retrieve a true-to-scale video stream of the dancer in the virtual world. With APIs provided by Intel RealSense SDK 2.0 Unity Wrapper, a depth texture and an RGB texture was bound to camera stream from Intel RealSense Camera. The depth texture's red channel represents captured depth with higher value representing a smaller depth and blackness representing out of range or loss of data (Figure 3).

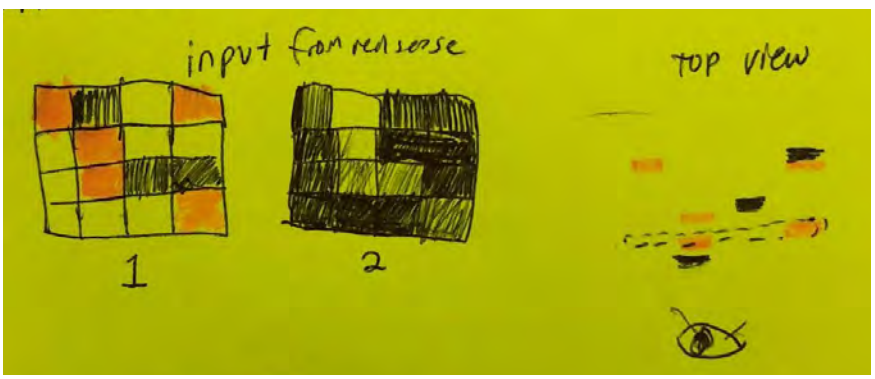
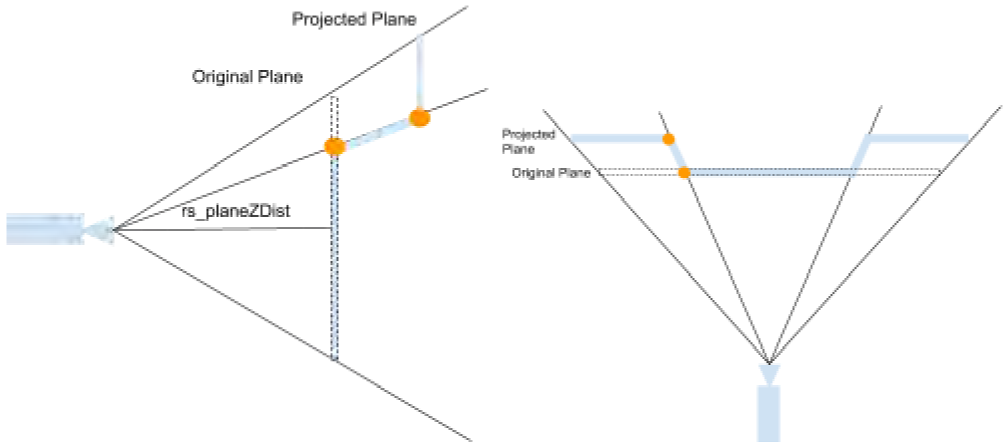


Figure: Visual Explanation of the Depth Texture

Both the current frame's depth texture and the previous frame's texture are bound to the shader. The shader itself is a fragment shader composed of three passes. The vertex shader part of the three passes shares part of the same process:

1. The vertex samples the depth texture color at the current vertex at the current level of detail.

2. The vertex shader then computes a perspective projection vector in the plane's object space with origin at the camera's position and pointing towards the vertex's position. The offset distance is determined by the depth value at the point. (Figure 4-5)



Figures 4 and 5
Plane Projection

3. The next step compensates for holes that exist on the depth texture due to surfaces parallel to the camera ray. If a hole exists, the shader looks for the texture color on the texture from the previous texture. If the previous texture also has a hole, the shader will sample towards or outwards the center of the uv for a maximum number of 10 steps of 1/30 decrement or increment in u and v coordinates, until it finds a valid depth information, and use the depth information for current vertex's depth information. If no depth information was found, the depth is set to the maximum value, which is 1.

4. The vertex shader will also compute a transparency value based on window size so that pixels outside the window will be transparent. The value is stored in a TEXCOORD structure and passed to the fragment shader down the pipeline

The shadow pass differs from the two lighting passes with one additional computation in the vertex shader:

5. The vertex shader will rotate each vertex around the object's x-axis, compute the vertex's world space position, and offset the points so they are on the ground. The vertex shader will also compute a scaling factor which will increase as the object gets closer to the ground so that the shadow appears to be bigger.

The fragment shader part of the two lighting passes share the same process:

1. First, the fragment shader uses an image edge detection algorithm to detect the edge of depth changes on the depth texture. Per each depth change, the fragment shader discards the pixels on the edge so there are no stretched pixels between two depths.
2. Calculates the lighting condition based on either the diffuse and ambient lighting or each lighting sources using a half-lambert model.

The fragment shader of the shadow pass does not compute any lighting, instead, it multiplies its color with whatever is already on the render texture.

Data Collection

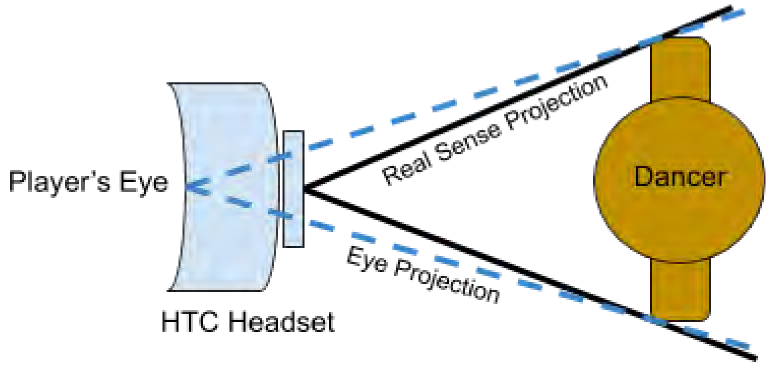
Both qualitative and quantitative data was collected in the user study.

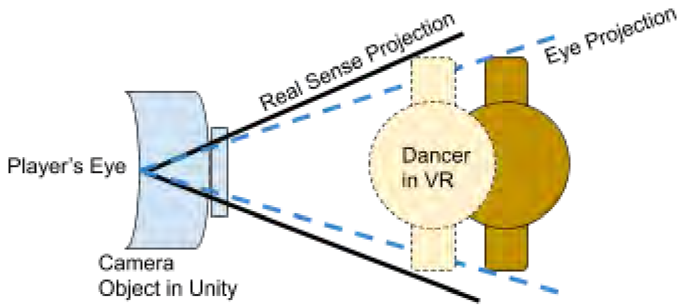
With the data collection component enabled in the Unity Game Engine hierarchy, the following data is recorded into a CSV file per 0.1 second: game time, two player's trackers' positions, two dancer's trackers' positions, headset's position, averaged player's tracker's proximity with dancer's tracker, calculated alignment of camera direction with dancer - player's relative position, and tracker speed.

Technical Limitations of Current Version

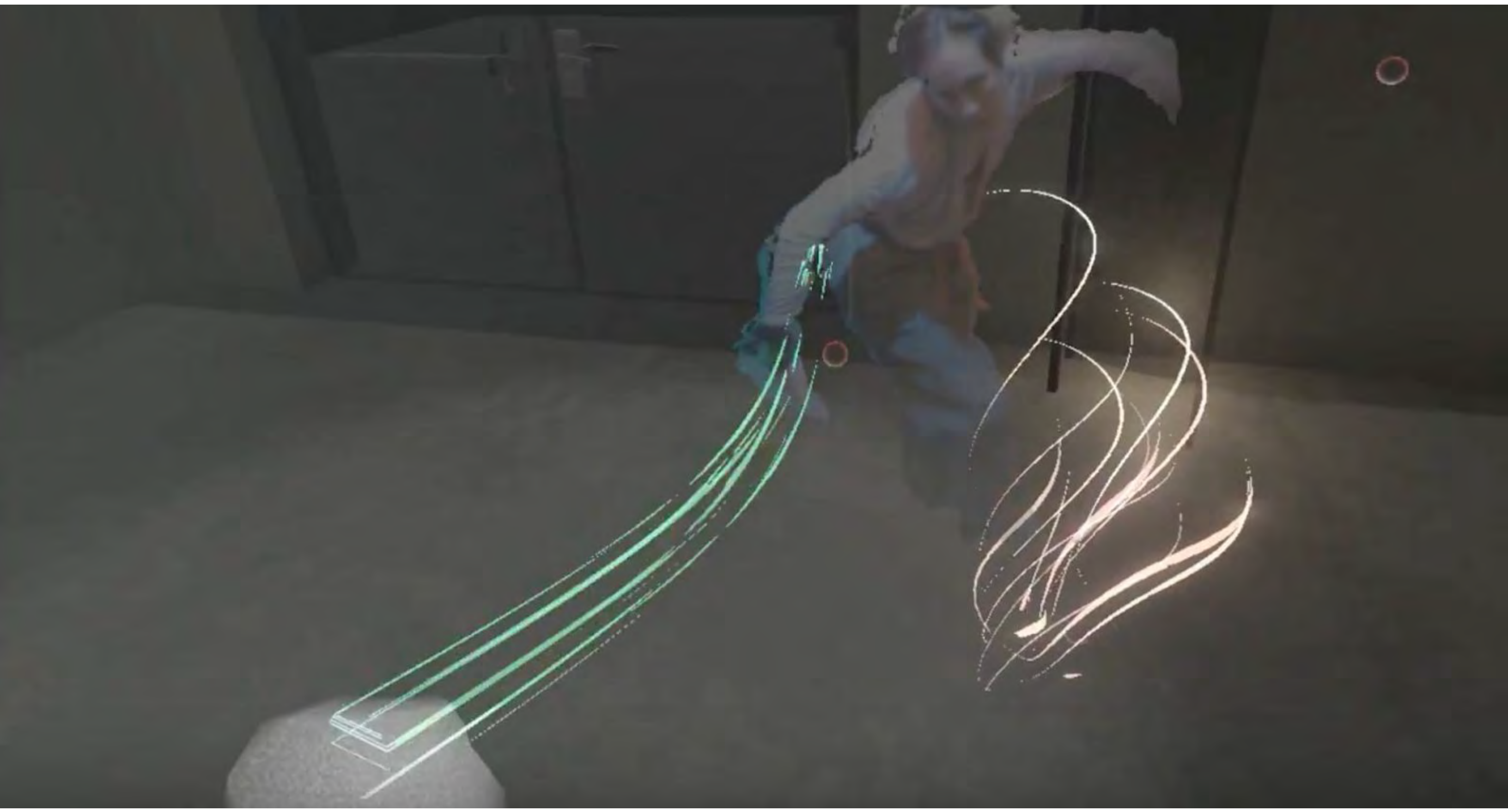
1. In the experience, when the camera feed is active in addition to the dancer's particle and multiple volumetric lights in the scene, there is a minimal visible delay in the camera feed following player's head rotation. The delay may be caused by the exhaustion of processing capability. Further optimization in both graphics and algorithms is needed to be conducted on this project to increase performance.

2. In our playtest, players reported that the dancer's location seemed to be far away from them comparing to the dancer location in the real world. This issue is caused by the dancer's reprojected location not being aligned with their real-world location. Currently, the dancer's projected location can be adjusted using the Depth Scale parameters on the shader. The offset that the player reported may be due to the manually calibrated position does not align with the position in the real world. Future researchers interested in implementing the same technology should consider working on getting the dancer's image projected to the correct location without manual adjustments. One reflection from this project is that the distance between the RealSense camera and the player's eye may also need to be considered. The dancer's image is projected into the virtual world using the same perspective that RealSense camera uses in the real world. Since the RealSense camera sits in front of the headset, the distance between the camera and the dancer is smaller than the distance between the player's eye and the dancer. When projected into the virtual world, even with the correct depth scale, the dancer's image would still have an offset from its location in the real world. The problem could be very obvious when the dancer is close to the player.



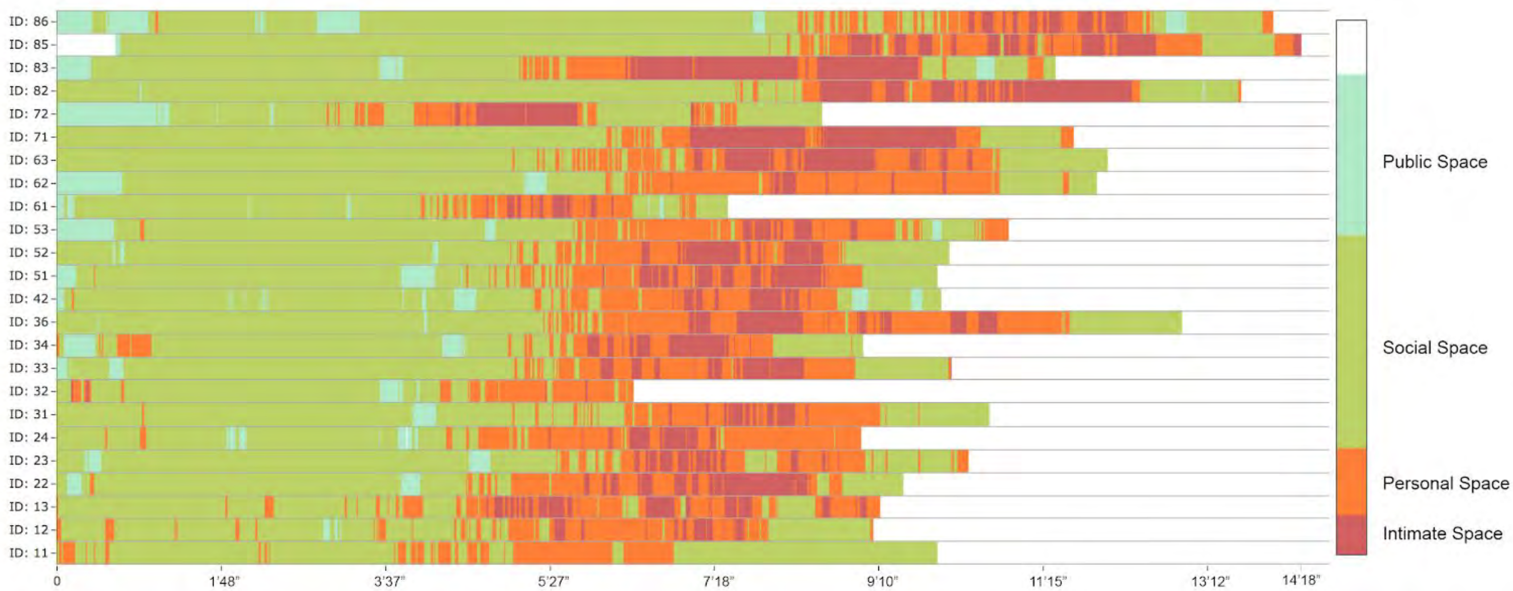


3. In addition, the Vive trackers did not respond very well during the Virtual Orientation Exercises (C) phase when the players rotated and moved their wrists and arms in front of their eyes. One assumption on why this phenomenon is happening is that the RealSense camera's infrared would interfere with Vive's infrared tracking. The problem may be solved by switching to a depth camera that uses stereo depth tracking.
    a. Experience design adaptation to attempt to mitigate this through telling participants it may be sticky, so they know it wasn't their fault and to create expectation that it may be "weird" and also to swing their arms a bit because it seemed to track better when they were making faster / bigger movements rather than slower / smaller movements. - smaller movement not enough relative movement to the environment so it gets confused about its position.
    b. Also more helpful to have slowdanger be able to speak to the participants live rather than the pre-recorded audio - all part of the facilitation of the experience, smoothness and sense of "being guided / taken care of"



4. Findings

4.1.1 Wake: Proxemics Over Time

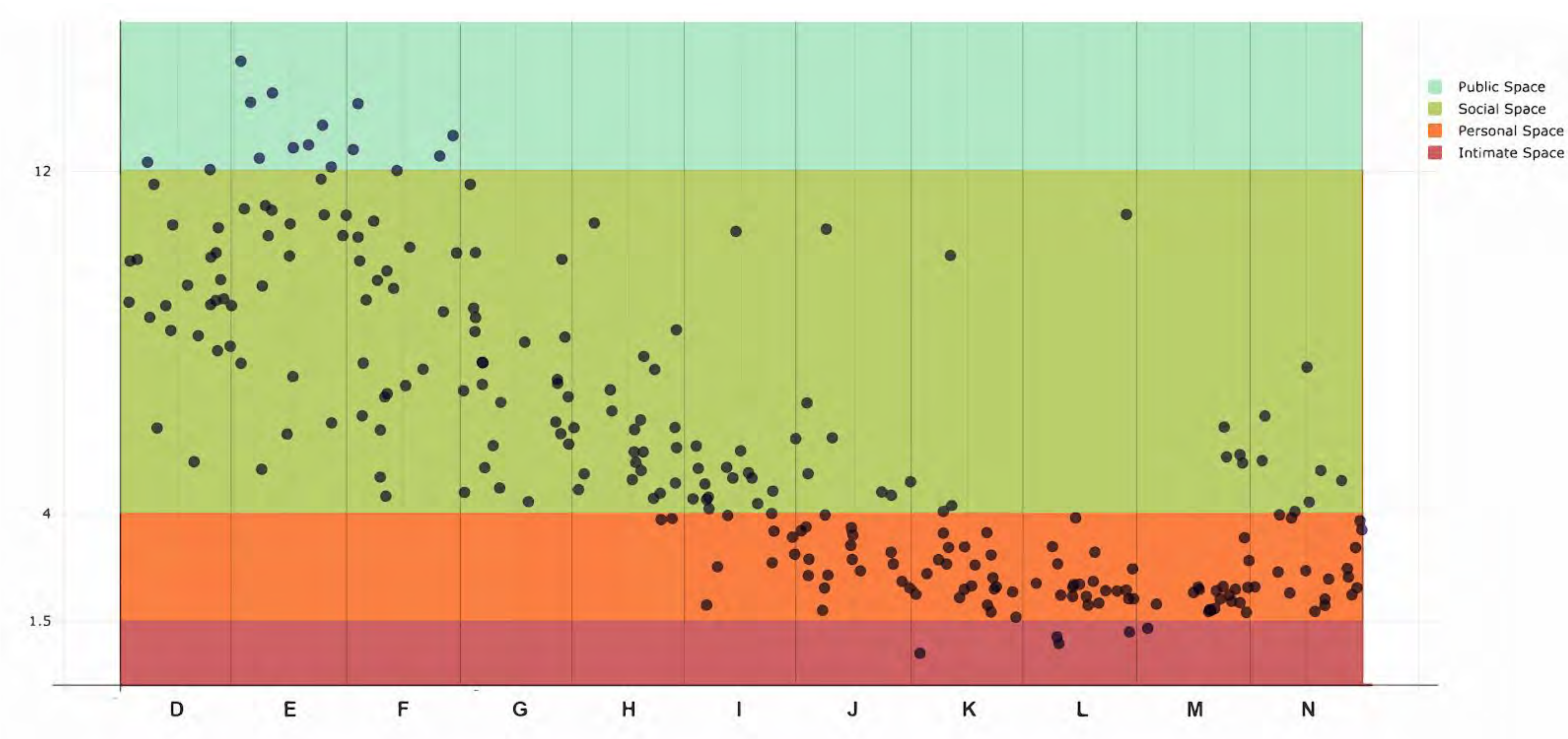


Heatmap: Participant Proxemic measurements during *Wake* experience. Y axis is participant ID, and X axis is time.

In this heatmap, we can see that the experience flow generally goes from social (lime green) to personal (orange) to intimate (red) space. The experience is intended to lead you to increasing levels of closeness, from social space, to personal space, to intimate space, and then explore space freely (when we go back to lime green, we're not intentionally trying to get them back to social space - the camera is deactivated so the participant is back in fully virtual environment.).

What is worth noting here is the flicker (or dither) between lime green and orange, when crossing the boundary from social space to personal space. Here, there seems to be some back and forth as if the participant and dancer are negotiating an entrance into each other's personal space. As we know from our lived experience, the boundary between interacting with someone socially, to intersecting each other's personal space, is a significant one. This boundary is not always respected, and requires communication through subtle embodied cues or language. The dithering seen here between social and personal, quantitatively, seems to reflect a mediated experience of this boundary negotiation.

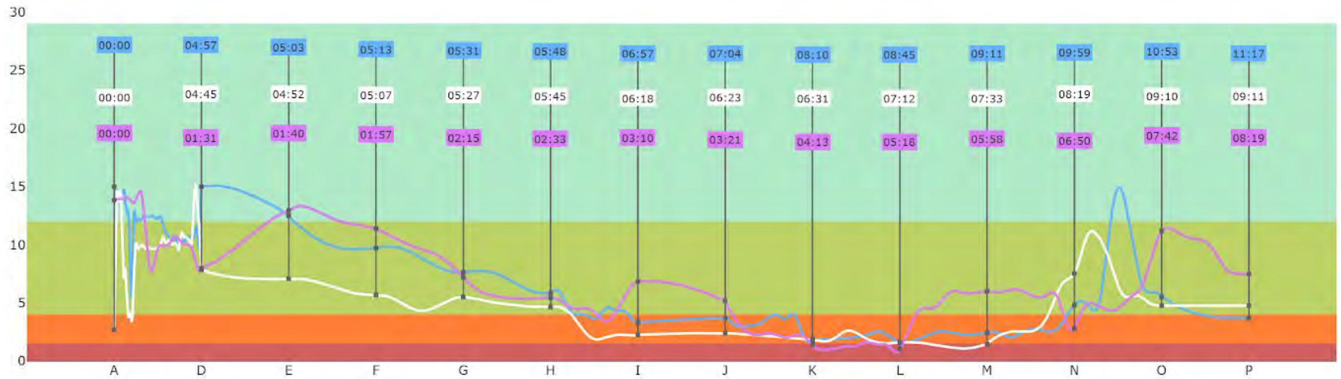
4.1.2 Wake: Proxemics By Event



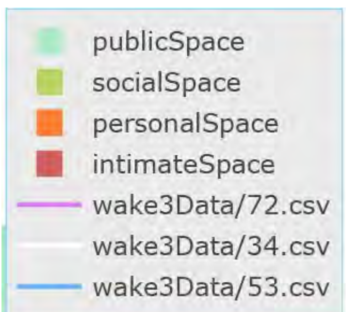
Scatterplot: Y axis is Distance (ft), X axis is Wake Journey Event (D-N)

Different proxemic spaces are associated with different journey events. This scatterplot shows the trajectory over time of decreasing interpersonal distance, beginning when the dancer is visible in the abstracted particle system (D), being revealed in the camera (I), moving together without touch (J), moving together with touch (K), and interacting with the sandbox (L, M), before turning around to explore their path (N) and the dancer's image fades.

4.1.3 Wake Proxemics: Comparing Individual Participant Journeys



Data Visualization: Sparklines for three participant journeys overlaid and mapped according to timecode and proxemic distance between dancer and participant.



Legend

This graph represents three different individual user journeys, showing proximity trend over Journey Event, with the individual time labeled at each Journey Event. This graph demonstrates that the proximity between participant and dancer tends to follow a similar trend, though the time each participant spends in each Journey Event can be significantly different. The transition from social space to personal and intimate space seems to have the most significant variation, especially at Journey Event (I), which is the moment the Intel RealSense camera was turned on to reveal the dancer. Some participants moved much more quickly towards the dancer, and others remained in the proxemic zone of social space for longer. Participant 72, for instance, represented by the pink line, remained more in social space during event (I) and event (M) when the other two participants visualized in this graph were fully in personal or intimate space. This may signify differing levels of comfort with the scenario or the co-presence involved. Further analysis would be needed to draw deeper conclusions about this.

4.2 Key Theme: Trust

4.2.1 Quantitative Data

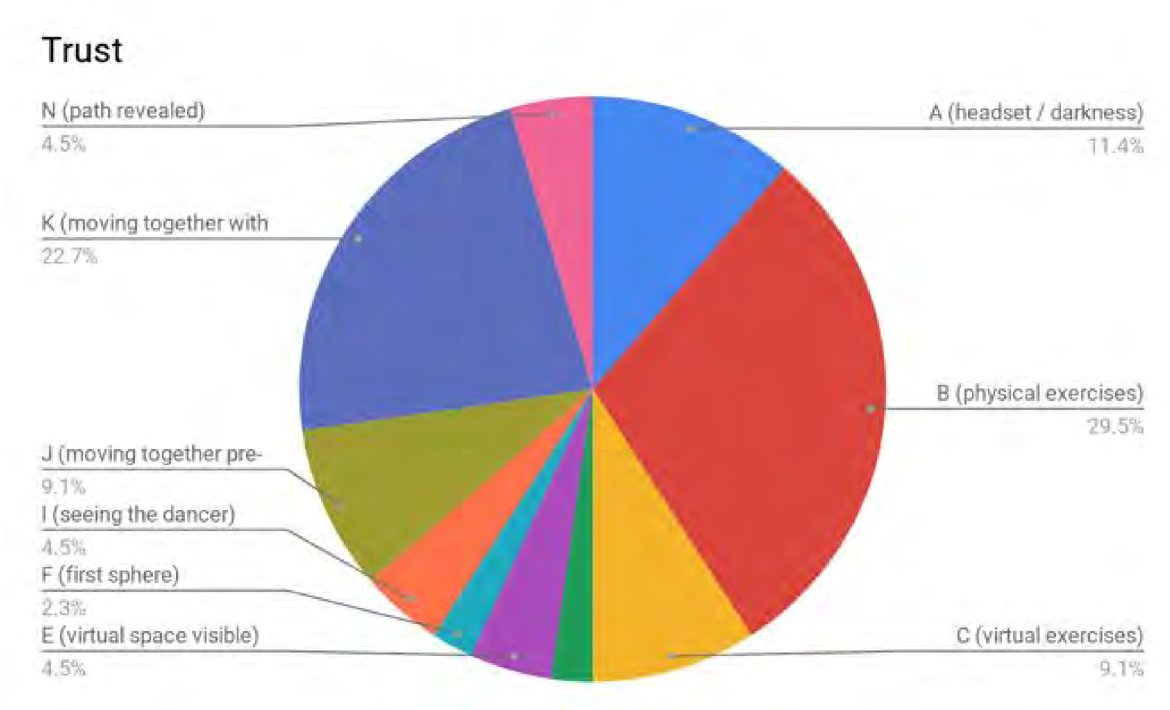


Figure 6.
Pie Chart illustrating Trust and Associated *Wake* Journey Events

KEY INSIGHT:
Trust in *Wake* emerges through facilitated embodiment.

MOST COMMON CORRELATION:
In the most common journey event evoking trust, 13 out of 25 participants identified trust with the Physical Orientation Exercises (B).

One participant said, "The short breathing exercises at the beginning helped re-focus my body so I felt more comfortable wearing the headset, and the initial feeling of apprehension started to fade away."

OTHER COMMON CORRELATIONS:
The second-most common journey event evoking trust, 11 out of 25 participants identified trust with the experience of moving together with the dancer, in which they could both see and touch the dancer.

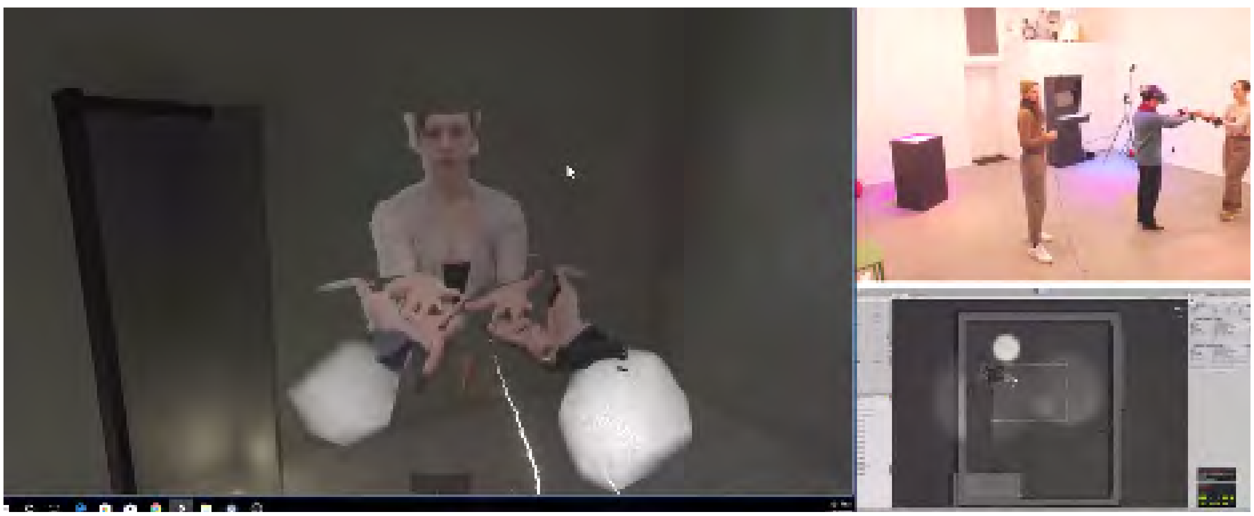
Instances of trust in which participants could only *see* but not *touch* the dancer were lower (9.1% vs 22.7%) than those in which physical touch was involved. This appears to indicate that tangibility is an important aspect of determining the trustful nature of a co-present virtual experience which implicates interpersonal communication.

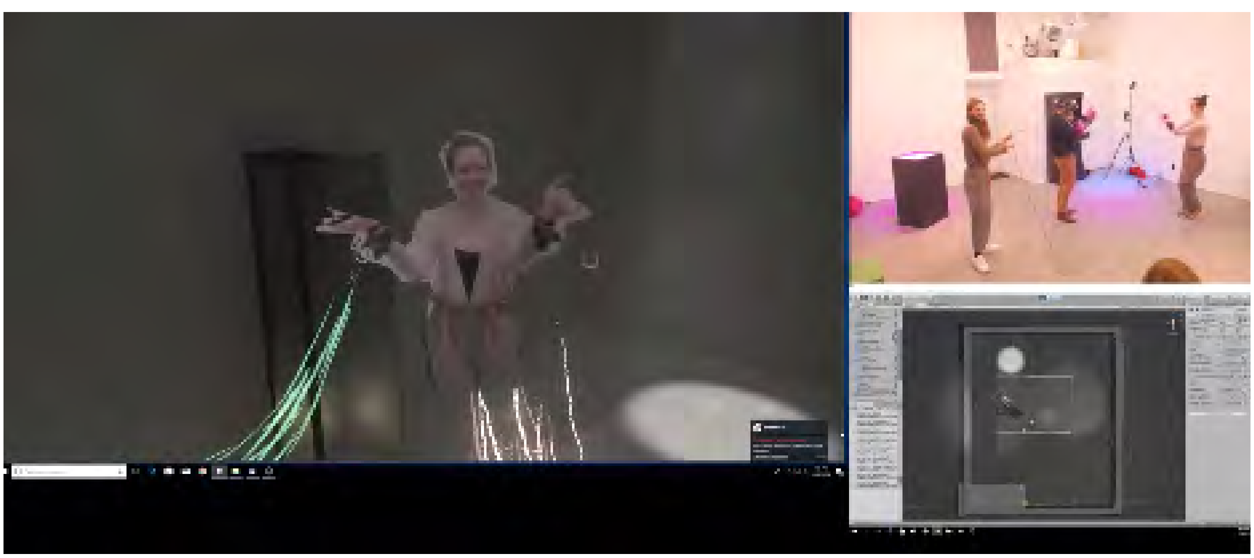
In the case of purely telepresent scenarios (in which co-present participants are physically distant), this may be a productive space to explore the use of haptic feedback to simulate sensations of co-presence and touch. However, in order to develop conclusive evidence regarding this, multiple issues would need to be further examined, or factors isolated, which were NOT considerations in *Wake*, such as the correlation between human skin-to-skin contact (i.e. in Wake: hands, fingers) and trust vs. synthetic materials.

Trust and touch will be further examined in the following Discussion chapter.

4.2.2 Qualitative Data

Trust in *Wake* from a qualitative perspective will be discussed in-depth in Section 5.2, in the following Discussion chapter. We collected qualitative data in the form of phenomenological interviews following the *Wake* experience.





Figures: Video data collection. Left, in-headset view, top right web cam in the physical room, bottom right isometric view of Unity game engine with virtual environment.

5. Discussion

5 Contributions

As XR experiences become an increasingly common media platform used by various media creators — such as filmmakers, journalists, video game creators, brands, and performers — new principles of design emerge. These design principles are developed across user experience, interaction design, and spatial/environment design. Like other new mediums, the early experiments and commercial offerings begin to set standards and perpetuate methods and strategies which filter into future output - from the affordances of the tools the creators use, to the industry's perception of what will be commercially successful, to whose work is funded, and to the quantitative and qualitative research conducted to test and affirm these methods and products.

With this in mind, and addressing a gap in the literature and available content for co-present mixed reality, *Wake* and its corresponding user study investigate head-mounted immersive experiences from the lens of phenomenological and affective experience, embodied interaction design methods, and social presence. Informed by cross-disciplinary research in social and cognitive psychology, kinesthetic perception and improvisational dance, and real time graphics processing and volumetric capture, the knowledge and methods generated by this study contribute to new techniques in human-machine mediated communication and embodied interaction for head-mounted immersive experiences.

This study contributes the following:

1. Qualitative Insights into Co-Location and Co-Presence in Mixed Reality :
    a. Social Presence
        i. Proxemics and Shared Intentionality
            1. Dialogue with Previous Social Psychology Research
            2. Kinesthetic Perception and Collective Improvisation
            3. Trust
2. Phenomenological and Psychological Coding of Experience through Emotion Wheel and Interviews
    a. In-depth discussion of trust in ACLCPMR[70]
3. Embodied Interaction Design Techniques for Mixed Reality
    a. Physical and Virtual Orientation Exercises
    b. Discovery and Mastery
    c. Sensory Perception in XR
4. Technical Contributions: Intel RealSense Real-Time Streaming in Unity[71]

The sub-sections which follow consist of an extended discussion about each of the four contribution categories listed above.

Key Term: ACLCPMR
This thesis defines a form of *participant↔other* relationship within head-mounted immersive media, articulated as ACLCPMR, in which some configuration of people wearing headsets and others without headsets share space and a mixed reality experience. In ACLCPMR, both headset wearers and non-headset wearers may be tracked by sensors, either mounted on the headset, worn on the body, or by other computer vision or motion tracking technology in the space. This scenario will likely become a growing practice, and is similar to the asymmetric, co-located experience of collaborative work environments (as envisioned by Microsoft Hololens, or the hybrid media spaces described by

[70] See section 5.2
[71] See section 3.7

Dourish[72]), immersive performance environments (such as Punchdrunk[73]), or the increasingly common scenario of being co-located with someone using a phone or other mobile device who is simultaneously interacting with others who are not using a device. Regarding emerging ACLCPMR scenarios for entertainment, the formats of Location Based Experiences (LBE's) or other immersive performative or installation-based XR experiences may utilize this type of configuration for *audience/participant↔performer/other* relationships. Additionally, configurations of experience design which include audience who is waiting to enter a headset-based experience should be considered. Each of these different scenarios incorporates an asymmetric relationship with human-machine mediated communication, yet each has different qualities of immersion, social interaction, and makes different cognitive demands. These topics point to promising areas of cross-disciplinary further research.

Wake is an ACLCPMR experience which utilizes a facilitated *participant↔performer* configuration.
The acronym CLCPXR (i.e. co-located, co-present XR) serves as a method of describing the spectrum of co-present XR experiences which implicate co-located participants, but are not necessarily asymmetric, and could be considered VR or AR, rather than MR. The taxonomy of immersive media, or recently favored term, "spatial computing," is an evolving dialogue and the terminology used here aims to be as descriptive as possible for both present and future designers and researchers.

5.1 Social Psychology and CLCPXR

As XR experiences swiftly move from the lab and into the lives, homes, and entertainment experiences of a wider audience, a new industry takes steps (and missteps) towards viability and longevity. This increased access, in conjunction with the current culture of social media and globalized communication, has generated efforts to create successful virtual environments which aim to enable social interactions (exemplified by the emergence of platforms such as Facebook Spaces, AltSpace VR, VR Chat, Normal VR, Rec Room). Understandings of social psychology, and its relevance to the theory and practice of embodied interaction design within computer mediated communication should be re-examined in relationship to this currently shifting media landscape of immersive experiences in which social affordances are involved. Elements to examine include social and interpersonal interactions within an augmented or mixed reality environment in which virtual objects merge or conflict with physical objects, and interaction design utilizing possible combinations of computer-controlled virtual agents, human-controlled virtual avatars, pre-recorded volumetric capture, and real-time streams of co-present people. The knowledge gained from these studies can be utilized to develop design procedures and user experience methods for this emerging industry that facilitate effectual immersive experiences. A framework for investigating social psychology in XR with particular relevance to the *Wake* design probe is proxemics and equilibrium theory. Utilizing these frameworks within the context of the ACLCPMR *Wake* experience, involving worn spatial sensors and real time representation of co-present people, generated significant findings regarding trust, which will be discussed in depth in the following sections.

Proxemics and Equilibrium Theory

As discussed in the Methods Chapter, *proxemics* is the study of interpersonal space which correlates physical distance with psychological levels of implied intimacy at four levels, in which intimacy (consensual and non-consensual) increases as physical distance decreases (i.e. public space, social space, personal space, intimate

[72] Dourish, Paul. *Where the action is: the foundations of embodied interaction*. MIT press, 2004. p. 150.
[73] Discussed in Section 2.4

space). Proxemics examines human nonverbal communication corresponding to affect and levels of comfort felt by physical proximity. The study of proxemics in walkable, co-present XR environments for multiple participants has renewed relevance with the emergence of location based experiences (LBE's) and other CLCPXR scenarios which utilize head-mounted devices.

Equilibrium Theory[74] is a psychological theory regarding eye contact as it affects social interactions, developed by Argyle and Dean in 1965, in which eye contact is linked to motivation for affiliation between two people, and an equilibrium in physical proximity, eye contact, and intimacy is reached based on the forces of approach and avoidance in which interactions are negotiated. This theory discusses an inverse relationship between eye contact and interpersonal distance[75], though the most relevant aspect of this theory to the *Wake* findings is the articulation of the importance of eye contact as nonverbal communication in social interactions, substantiated by the participant reports of mutual eye contact in *Wake* (i.e. 24 out of 25 participants reported feelings of mutual eye contact with the dancer while wearing the headset). Further research building on the *Wake* study would collect quantitative data using gaze tracking in order to specifically target findings regarding the frequency and duration of eye contact as correlated to interpersonal distance (as tracked by Vive trackers) within ACLCPMR. This additional data would be able to draw more informed conclusions that would substantiate or refute Argyle and Dean's theory in relationship to Bailenson, et. al.'s work with immersive virtual experiences.

The cognitive psychologist and XR researcher Jeremy Bailenson and the social psychologist and technology researcher Jim Blascovich, developed a method for studying social influence and interactions in immersive virtual environments on which they published widely from 2000 - 2012. Studies utilizing proxemics and the Equilibrium Theory, specifically mutual gaze, within virtual reality from the early 2000's by Bailenson, Blascovich et. al,[76] investigate the experimental validity of using immersive virtual environments (IVE's) as a tool for studying social psychology, in which the IVE contains interactions which simulate (and are used to draw conclusions about) reality and human behavior. However, this does not consider co-present XR as a "real" social scenario in and of itself, and these studies are not without their flaws in methodology (i.e. presumption fallacies), and resulting conclusions, which will be discussed in the following subsection (5.1.1). It is time to revisit this topic[77] in light of the new circumstances in which XR increases in availability to the general public, and specifically in the context of the relationship between affective experience and embodied interaction.

Contribution: New Methodology

This thesis contributes a new methodology for calculating proxemics through distances between devices in real units using tracked sensors worn by participants. This may be a productive methodology for studying proxemics within CLCPXR, as previous studies were calculated only in virtual units. Additionally, the introduction of real-time streaming depth video (using the Intel RealSense) of a co-present person, i.e. the dancer in *Wake*, circumvents the uncanny valley encountered through the use of avatars (as in the Bailenson studies), which produces new findings

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[74] Argyle, Michael, and Janet Dean. "Eye-contact, distance and affiliation." *Sociometry* (1965): 289-304.
[75] The proxemics data collected in *Wake* would appear to suggest that the eye contact experienced by participants may be related to closer proximity, rather than more distance between the participant and dancer (as the Equilibrium theory would suggest), though this could be due to a conflation of this theory with an experience designed to create a situation in which participants are encouraged to move closer to the dancer (as in *Wake*). A full analysis of this theory would require further research in which variables were more clearly separated and empirically defined.
[76] Bailenson, Jeremy N., et al. "Equilibrium theory revisited: Mutual gaze and personal space in virtual environments." *Presence: Teleoperators & Virtual Environments* 10.6 (2001): 583-598.
[77] Bailenson, et. al, does continue to write on this subject with the expanded understanding of virtual environments as social experiences which do not replicate reality, but are as in this paper:
Oh, Catherine S., Jeremy N. Bailenson, and Gregory F. Welch. "A Systematic Review of Social Presence: Definition, Antecedents, and Implications." *Front. Robot. AI 5: 114. doi: 10.3389/frobt* (2018).

about human social interaction in co-present XR, in which an examination of trust emerged most significantly. *Wake* utilizes quantitative and qualitative methodologies to investigate emotional and affective experience within ACLCPMR, and aims to fill a gap in the literature regarding XR and social presence, trust, and embodied interaction.

5.1.1 Defining and Operationalizing Co-Presence

Reconsidering Bailenson, et al.

In the early 2000's, a body of literature was produced in which social psychology and cognition were examined in relationship to developments in virtual reality regarding the use of embodied agents or avatars and their effects on perception of co-presence and social behaviors [Bailenson, Blascovich, 2001, 2005]. The definition and operationalization of the term co-presence varies greatly within this research, and deserves further examination than this thesis provides.

For an experience to feel co-present, it could be argued that the participant must believe (or suspend disbelief) that the other person (or character) is "real," "alive," and participating in the same experience as them. If this other presence is represented as a humanoid (and treated, or expected to be treated, as another human being), then the visual and behavioral aspects of this human must be perceived as authentic.[78] The "uncanny valley" is a recognized phenomenon which refers to the emotional response to a humanoid representation which is close to, but not quite accurate, eliciting sensations of strange familiarity and sometimes revulsion. I argue that in order to study and draw conclusions about human behavior in relationship to other humans (i.e. social interaction) virtual human avatars or agents cannot be substituted for real people in these experiments, no matter how high the "photographic" or "behavioral realism" claims to be. Bailenson does address an aspect of this issue in the 2005 paper, "The Independent and Interactive Effects of Embodied-Agent Appearance and Behavior on Self-Report, Cognitive, and Behavioral Markers of Copresence in Immersive Virtual Environments."[79] This paper articulates that misleading conclusions can emerge from behavioral assessment concerning co-presence without considering the appearance of the avatar or embodied agent. This paper also describes that the definition of co-presence is a contentious topic in which the way the term is defined affects the results of the experiment.

As this lineage of research makes clear, co-presence is an operationally and definitionally complicated topic that has multiple interpretations. This means that the emergent research on co-presence and social interactions in XR is even more crucial to be done with a clarity of definition and a strong cross-disciplinary dialogue with current social, cultural, and other factors taken into account when bringing in other research to substantiate claims and push the development of technology forward. For instance, proxemics is a topic recently in the news again[80] (2018-2019) due to a strong re-negotiation of social, political, and gender-based behaviors in which issues of personal space, touching, and consent are being brought to light, revealing a pervasive culture of oppressive hierarchies and abuses of power, causing a shift in the societal acceptance of previously held structures of interpersonal behaviors.

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[78] This statement is as assumption based on my current research, and would need to be validated through further empirical research.

[79] Bailenson, Jeremy N., et al. "The independent and interactive effects of embodied-agent appearance and behavior on self-report, cognitive, and behavioral markers of copresence in immersive virtual environments." *Presence: Teleoperators & Virtual Environments* 14.4 (2005): 379-393.

[80] See "Me Too" movement and https://www.nytimes.com/2019/04/04/health/psychology-metoo-biden.html, Accessed April 4, 2019.

Coming to a fully researched conclusion about the exact nature and operationalization of co-presence in relationship to this research lineage and situating my research within it is beyond the scope of this thesis, but this inquiry into the complex area of social psychology and its relationship to XR technologies has opened many questions that would help guide further research. However, given our data gathered from the participants in terms of trust and the presence of the dancer, facilitator, and sense of embodiment of the participants, we can draw some conclusions that our methods were able to generate genuine social interactions within an experience in which an affective shift from anticipation to trust was reported by a significant number of participants. What follows is an in-depth discussion of trust within *Wake*, which serves to begin to answer the questions of design methods for creating embodied and social interactions within ACLCPMR experiences.

In the previous proxemics research[81], the issue of “realism” is addressed by demonstrating humanoid representations at varying levels of realistic representation, and findings are described which align with those of social psychologists working in real-world (i.e. non-virtual) scenarios. However, they do not directly articulate the possibility that a significant finding - the inverse correlation of mutual eye gaze and interpersonal distance - could be affected by the feelings of revulsion experienced by a participant when encountering a virtual agent or avatar which would fall within the “uncanny valley” territory. The image below shows images of the virtual humans used in the 2003 Bailenson, et. al. study, which can clearly can be seen to have significant differences, both visually and behaviorally, from real people.

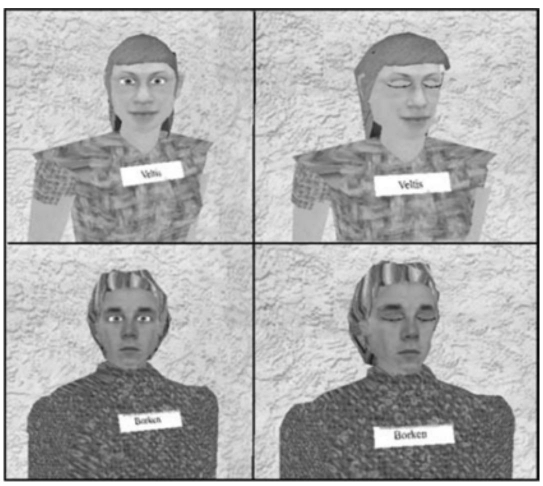


Figure: Male and Female virtual humans used in “Interpersonal Distance in Immersive Virtual Environments” study.[82]

The concept of *behavioral realism* is introduced as a spectrum assigned to the avatars used in the study, and these avatars are claimed to have had high behavioral realism. A *behavioral scenario* describes the action happening within an experiment, and what participants are expected to do. In this study, the avatars performed certain actions such as looking directly at the participant, blinking, and turning their heads. However, the avatars were not communicative in the same way as a real person, though the findings in the study were presented as comparable to real world social scenarios. In *Wake*, however, the co-present dancer was rendered in real time through the depth camera, unaltered, which I propose generated more legitimate findings concerning human social presence due to both behavioral and photographic realism as unaltered from real life, except for the layer of mediation from the VR headset. This means that what is being studied in *Wake* is genuine human co-presence, specifically *within* this

[81] Bailenson, et al. 2001, 2003, 2007.
[82] Bailenson, Jeremy N., et al. "Interpersonal distance in immersive virtual environments." *Personality and Social Psychology Bulletin* 29.7 (2003): 819-833.

context of mediation through the immersive technologies involved, and not as a replica for an un-mediated scenario, as the previously discussed research claimed.

Lineage and Longevity of Social Psychology Theories

Argyle and Dean's theory was created within a specific social, historical, and political context. Does this research carry forward to today? How does social psychology research adapt to changing social conditions over time or geography? What is the "shelf life" of social psychology research, especially when it comes to describing behaviors along a gender binary in which gender roles are ascribed to specific cultural and biological factors? How responsible is it to use these theories unaltered and apply them to research today? Or in the 2000's when Bailenson, et. al. was working? Does the social psychology need to be updated in order to utilize these claims as a basis for further study of a developing technology? This brings Donna Haraway's argument in her essay "Situated Knowledges" to mind in which she argues that claims to "scientific objectivity" have been dominated by a "closed doors group" of white males and that the subjective experience, or "partial perspective" of marginalized others have been left out. Hence, the research perpetuates narrow or false claims of what is "true" or "objective" regarding the subject matter. It would appear that there is a manifestation of this problem at hand in the research lineage and trajectories of the connection between social psychology done in the 60's and the VR research happening in the 2000's at Stanford, and still continuing today. Therefore, the technology develops along a path that remains limited in its perspective, and the resulting content and technological advances and strategies perpetuate these narrow claims and participate in the chorus of their own echo chamber.

The Uncanny Valley and *Wake*'s ACLCPMR Solution:
Real-Time Telepresent Streaming, Proxemics, and Co-Presence Contributions

Key Contribution: The *Wake* study calculates distances between devices in real units using tracked sensors worn by participants. This may be a productive methodology in the future as previous methods calculated in virtual units only.

Encountering an uncanny human representation makes people uncomfortable, as demonstrated by the concept of the "uncanny valley." The *Wake* study may contradict previous findings which claim that eye contact is uncomfortable specifically in the context of virtual avatars vs real people. Other factors are bound up in this claim, such as a co-present person's friendly approach, attitude, and the co-located aspect of touch, and the way touch contributes to a sense of trust. This will be examined further in the following sections containing an in-depth discussion of trust.

Wake involves other real people, who are both co-located and co-present. Therefore the proxemics measurements are based on real-world locations perceived through a mediated ACLCPMR experience. In this study, interpersonal closeness within proxemics zones of personal and intimate space were correlated with an increased sense of trust and mutual gaze, which contradicts the findings of the Bailenson study.

Wake is explicitly designed to create conditions in which a participant can experience a heightened sensory or perceptual awareness in a manner that cultivates trust and invitation to participate, and minimizes distractions caused by concerns of personal safety or intentions of co-present individuals.

My findings indicate an increase in trust with eye contact in IVE (immersive virtual environment). This increase in trust with eye contact corresponds to decreased interpersonal distance, as demonstrated by the proxemics data outlined in the Findings chapter[83].

An unanswered question remains: how much were participants impacted by the dancer "inviting" them to move with them, i.e. how much does the physical distance correspond to participants "following instructions"? This concept is elaborated by the participants who reported that they "chose" to follow the instructions, cultivating expectations of user agency, the negotiation between the dancer and the participant, and the experience flow which cultivated the increased trust and emotional response in the participant, allowing them to have a transformative experience in the XR environment. Future work in gaze tracking would help to more accurately track this data with (perceived) mutual gaze. Additionally, it is worth mentioning that the dancers I chose to work with, *slowdanger*, are trained in improvisational dance, and regularly work with non-dancers in physical movement classes. A contributing factor to the dancers being able to realistically respond to the participants in a scenario in which they purposefully attempted to simulate eye contact, even though the dancers could not see the participants' eyes due to being blocked by the headset, was that the dancers could respond to the participants' movements with high accuracy and kinesthetic empathy, which added believability and closer connection to the participant <> dancer evolving relationship. Being trained in anticipating and responding to movement through subtle physical cues from another person is a strong skill for both Anna Thompson and Taylor Knight (*slowdanger*).

Streaming RGB+Depth Video in Real Time

Figure: In-headset view of co-located, co-present dancer (Taylor Knight) streamed through Intel RealSense camera. Dancer and participant can interact with shared virtual objects which participant sees in-headset, and dancer sees on external monitor in the physical room.

The *Wake* study contributes a new method of streaming a real-time RGB+Depth video of a co-present person, instead of using an avatar or virtual agent. This circumnavigates the uncanny valley, which produces new findings

[83] See sections 4.1.1, 4.1.2, 4.1.3.

about human social interaction in co-present XR. One of the major findings using this method concerns trust, which will be discussed in the following section.
These previous studies did not include phenomenological data - just quantitative data. The claims here are more than just empirical phenomena; there are many factors at work here. Given this problematic space of exploration, exploring co-located co-presence in an installation format will help us understand these additional factors more fully. Specifically, I contribute a connection between theories and practice of embodied interaction and embodied cognition, in the context of emerging immersive head-mounted XR experiences.

Interpersonal distance in virtual environments has been examined by Jeremy Bailenson, et. al.[84] but only in reference to virtual co-presences of computer generated avatars. *Wake* involves other real people, who are both co-located and co-present. Therefore the proxemics measurements are based on real-world locations perceived through a mediated ACLCPMR experience. In this study, interpersonal closeness within proxemics zones of personal and intimate space were correlated with an increased sense of trust and mutual gaze, which contradicts the findings of the Bailenson study.

A possible conflict in the findings involves familiarity with the dancer and facilitator, i.e. which participants were strangers to slowdanger, and who knew them previously? How did their experiences differ? I could have studied this difference specifically, or recruited only participants who did not know slowdanger personally, but I didn't, and this leaves room to study these factors in further research.

Factors that moderate personal space include: culture, race, physiology, age, interpersonal relationships.[85] Factors within XR experiences that moderate personal space include: priming, comfort with hardware, fidelity of representation of people (realistic avatar vs abstract or fantasy avatar vs real-time camera), trust in the hardware, sense of "freedom of movement" in participant - i.e. physical integration and comfort, consent and participant agency to choose how and when to move and engage with another, experience design, fidelity of tangible environment and unification with virtual environment.

The Wake user study relies on behavior of confederates, whose behavior will inevitably vary to differing degrees. However, but another word for confederate is performer, as in a live experience. In this way, *Wake* directly straddles the line between immersive theatrical experience, virtual experience, human computer interaction experiment, and social experience.

In Bailenson's studies using humanoid avatars, he refers to the degree of *behavioral realism* and *photographic realism* as contributing factors in participant response to the avatars. Regarding the Degree of anthropomorphism, he hypothesized that behavioral realism would have a larger effect on proxemic outcomes regarding mutual gaze. [86] Studying the combination of virtual agents and co-located co-present real people would be interesting - and in direct dialogue with Bailenson's proxemics work.

Wake sidesteps the questions of photographic and behavioral realism entirely by utilizing the real time streaming depth camera to render a co-present person. Thus, co-presence was ultimately achieved not through simulation, but by the real time rendering of a co-located, co-present dancer. This method therefore successfully circumvented the uncanny valley problem, not by directly addressing the problems of photographic and behavioral realism in an avatar, but by side-stepping them altogether. Qualitative findings from the semi-structured phenomenological

[84] Bailenson, Jeremy N., et al. "Interpersonal distance in immersive virtual environments." *Personality and Social Psychology Bulletin* 29.7 (2003): 819-833.
[85] Bailenson, Jeremy N., et al. "Equilibrium theory revisited: Mutual gaze and personal space in virtual environments." *Presence: Teleoperators & Virtual Environments* 10.6 (2001): 583-598.
[86] Ibid. pp. 586.

interviews revealed that a vast majority of the participants (24 out of 25) felt that they were able to make and hold eye contact with the dancer as though it was real and mutual, despite knowing that the dancer was not able to see their eyes (due to the headset physically covering their face). The findings in *Wake* therefore plausibly suggest that real-world, genuine social interactions are possible within hybrid media environments like VR. More importantly, they suggest that ACLCPMR not only stands as a viable method for achieving experiential optimization when it comes to representing others in VR, but also for testing, researching, and developing new forms of human-machine mediated communication.

5.2 Trust

Trust was the most common emotion identified by participants using Plutchick's *Emotional Wheel*. 25 out of 25 participants chose Trust as one of their 5 emotions in the semi-structured interview.

Two main types of trust were identified within Asymmetric, Co-Located, Co-Present Mixed Reality. Each participant must actively choose to trust the scenario to a certain (personally-determined) level in order to participate in the experience. Within the experience, more specific trust can be earned through direct embodied interaction. In other words, trust emerges through a precondition or a transformation.

The definitions articulated at the beginning of the thesis encapsulate these differences:

1. belief in a situation or person through conscious choice or the absence of fear
2. mutual reliability established as a consequence of direct action

The first type of trust is encountered at the beginning of the ACLCPMR experience. Many participants identified emotions of apprehension, anticipation, and acceptance at the beginning of the experience. Trust in this situation is an active choice made by the participant, instead of the alternative, to disengage from the experience entirely.

Every immersive experience will go through this first type of trust. This is the choice to put on the headset and step forward into the unknown.

The second type of trust is encountered through direct interaction with the virtual and physical environment and presences. This type of trust was found to emerge in multiple ways, such as through virtual spatial design, touch, and eye contact between participant and dancer. These themes will be examined in the following sections.

5.2.1 Trust and Embodied Interaction in ACLCPMR

As demonstrated by the quantitative findings regarding self-reported emotions and corresponding *Wake* journey events, specifically regarding the Physical Orientation Exercises (POE's) and the journey events, and Moving Together with Touch (K), it can be inferred that trust emerges through facilitated embodiment. The following subsections will discuss this in detail, as well as the affective nature of the physical-to-virtual phenomena and social scenarios involved in ACLCPMR.

5.2.1.1 Blindfold+

Head-mounted XR, and most significantly its MR (mixed reality) incarnation, re-situates us in relationship to our sense hierarchy, opening up new forms of experiencing space, materiality, the presence of others, and our own embodied cognitive processes. Mixed reality has many manifestations, as “realities,” or perceptual planes, can be mixed across multiple sensory channels. In Western traditions, vision is the most privileged sense in terms of ways of knowing and reasoning about the world. Head-mounted XR implicates a re-orientation of vision by covering our eyes completely with a headset. Through restricting our vision to the stereo-lenses in front of us, we heighten our other senses in order to straddle physical and digital environments. This requires us to negotiate new, blurred boundaries between our own bodies and the content we encounter. This process of orientation and comprehension is highly cognitively demanding.

In our conversations about trust, many participants describe feeling trust when they were being physically guided, and spoken to by the facilitator in the beginning of the experience. The context of having what is essentially functioning as “blindfold+” (physical blindfold plus the possibility of any image appearing) placed on one’s head can immediately trigger a sense of apprehension or anticipation, and could trigger sensations of claustrophobia or vulnerability. The physical guidance through touch, tangible connection to the world outside the headset, and spoken assurance helps to mitigate the apprehension or potential fear brought on by the headset.

Dancers, as a general assumption, are trained in body awareness and a proprioceptive “listening” to others as they move through space. This is a significant factor in their suitability as confederates in a study on embodied interaction, proxemics, and affect. The particular training of *slowdanger*, who not only are skilled at moving through space in a technical, choreographed or improvised way, but in regards to their sensitive awareness of others and their own physiological state. They bring a different form of embodied understanding and experimental inquiry into the topic.

5.2.1.2 Trust as a Spectrum

Participants also describe the trust as a process of negotiation, rather than a static sense of trust that remained at the same level throughout. Some participants described trust as steadily increasing over time, which may be attributed to the increased mastery of (or experience with) the mixed reality environment. Others describe trust and physical safety connected to the act of putting the headset on and being in darkness. Actively choosing trust in this scenario is a necessity to the experience. There is a spectrum from distrust to trust, where the participant consciously or unconsciously must evaluate the situation at hand, moment by moment, and determine what is happening and whether or not to trust the scenario. Being spoken to by the facilitator, physically guided around the room while being told that the purpose of this action was to assure the participant that there was nothing they could trip on, and told by the facilitator that they would place a hand on their back to help guide them.

5.2.1.3 Experience Flow: Onboarding and Offboarding

The order in which the experience is conducted is strategically designed to build upon itself and cultivate trust, agency, and embodied interaction with the participant. This will be further discussed in the following Design Implications section (5.4).

How the Headset Arrives : Onboarding

There is much subtlety in the choreography and improvisation of this interaction between the physically blindfolded, and therefore suddenly vulnerable, person in the headset, and the facilitator. The timing of the facilitation, both body and spoken language, and intersection with the personal, intimate space of the participant are all being negotiated simultaneously. This is reflective of the negotiations, decisions, and actions we make with others everyday. Trust is not simply a function of being in the headset long enough to feel “comfortable” with it. The way the headset arrives on the participant’s head, and specifically the attention to consent and intimate space, is directly implicated in the question of trust with immersive, head-mounted media. The specific hardware is of course a factor - in my research we used the HTC Vive Pro, which is first and foremost a virtual reality system, unlike Microsoft’s Hololens or other head-mounted AR devices, in which your eyes are not entirely covered. The Vive Pro fits snugly on the front of your head, and works best when there is no light leak - aka when the outside world is entirely obscured by the headset. For reference, the Vive Pro weighs approximately 470 grams.

How We Return : Offboarding

An immersive VR experience does not end abruptly once the user removes the headset. Just as becoming immersed entails a transition period (i.e., onboarding) in which the participant’s sensorimotor systems must calibrate to fit the sensorimotor demands of the virtual experience, the post-immersion experience likewise entails a transition period, an “offboarding” process, which entails a reorientation to the physical, unmediated environment and presences. As designers, we must therefore acknowledge that the participants will go through a reorientation period after taking off the virtual reality headset and other equipment, in which they will need to process or “decompress” from the experience. This means that we should create a scenario in which such processing may occur, either a quiet place for reflection, a medium for expression (such as a guest book), or a place to talk with other participants.

In *Wake*, offboarding involved the administration of semi-structured phenomenological interviews inquiring into four general aspects of the participants’ experience: (1) Bodily sensations, (2) Emotions, (3) Relationship to the dancer/facilitator, and (4) Interaction and spatial design. An interesting observation that was drawn regarding participants’ experience of offboarding in *Wake* was that there was a clear shift in vocal tone and language with most participants over the course of the interview. Their descriptions were initially highly intuitive and centered around bodily feelings and sensations, often spoken quietly almost as if they were speaking to themselves. Over the course of the interview, the vocal tone became louder, more directly conversational, and increasingly more analytical and deliberative. This transition from intuitive to deliberative language suggested that the the participants’ attention was initially largely preoccupied with various sensorimotor and embodied aspects of their immersive experience, and that the interview facilitated a sort of processing and integration of these aspects of their experience into their consciousness post-immersion.

5.2.1.4 Trust and Seeing the Dancer, Moving Together, and Touch: Mimicry, Agency, and Power Dynamics

The participants were asked about shifts in power dynamics and movement leadership over the course of the interactions with the dancer. When a participant is wearing a headset and another person is controlling visual elements in their field of view, a power dynamic can form in which the person in the headset submits to the control of the person outside the headset, i.e. the dancer. As we have discussed, the headset can act as a blindfold and physical burden which can generate feelings of vulnerability in the participant. However, often corresponding a participant's with feelings of comfort or safety in the headset, an equilibrium of agency can also be achieved through an evolving physical and verbal negotiation of action between the dancer and participant. Improvising movement with others requires the participants to cultivate a particular type of attentiveness to others. In a study conducted on kinesthetic togetherness in improvisational dance, "...this tuning-in aspect of moving together with one or more people is an essential part of the practice, often referred to as qualities of 'listening' or 'awareness' of self and others.[87]

For example (from participant interviews):

PI: Did you feel you were ever leading the movement?

Participant 11: Certainly.

PI: Did that swap?

Participant 11: Yes, and almost imperceptibly - as part of that dynamical system between us.

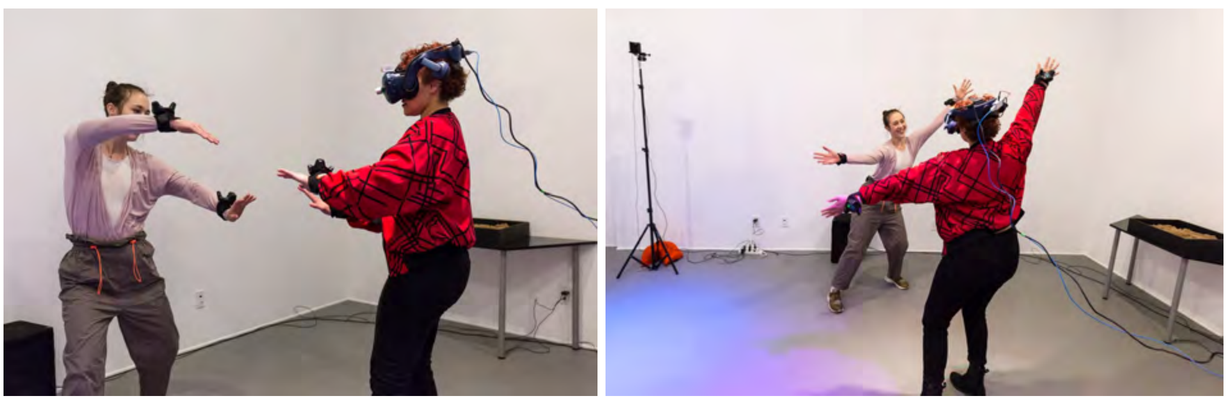


Figure: Participant (right) and dancer (left) improvise movement together.

Distinguishing Dancer as Co-Located and Co-Present, Not Pre-Recorded

It was not immediately apparent to all participants that the video of the dancer appearing in the headset was being rendered in real time, representing their physical co-presence with the participant. The process of realization that not only was the dancer being rendered in real time, i.e. not pre-recorded, but that the participants were also able to see their own hands if they held them within the field of view of the camera was a process with multiple contributing factors. In essence, the live streamed feed from the Intel RealSense could be considered a kind of telepresence within virtual reality.

Telepresence can be defined as the ability of a person to appear and to sense as if they were in a different place to their physically present location. Telepresence is a common phenomena, often used on a mobile phone, such as Apple's FaceTime, or on a laptop using Skype or Google Hangouts. These platforms generally use a camera to stream in real time a view of each participant's location, which is visible to all parties involved. In *Wake*, some

[87] Himberg et al., "Coordinated Interpersonal Behaviour in Collective Dance Improvisation." *Behavioral Sciences, 2018, 8, 23.*

participants made reference to the “window” of the Intel RealSense camera, comparing it to other telepresence platforms.

For example:
Participant 72: “When I realized that I could see my hands, but also that I was restricted to the extent that I could see my hands, there was that frame, it sort of felt like I was looking through a window into another world, but I could manipulate that window and see multiple perspectives that I could control.”

Multiple factors contributed to determining the “liveness” of the rendered camera stream. As illustrated above, the recognition of a participant’s own hands was a clear cue that the experience was live. If the dancer was visualzied before the participant hands, then four main factors were found to contribute to the identification of the real time, co-located dancer.

1. Sensation of eye contact, subsequent emotional response in facial expression and body language
2. Movement mimicry between participant and dancer
3. Hearing movement of dancer, i.e. footsteps or rustling of clothing
4. Touching the dancer

Eye Contact

Key Quantitative Insight: 24 out of 25 responded “yes” to the question of mutual eye contact.

Key Quote: Participant 62: “I think I tried to communicate with my eyes even though I knew they were not visible.”

Key Quote: Participant 24: “I don’t think you can have that kind of connection without eye contact.”

Some participants reported that the headset allowed them to make eye contact without social awkwardness. This seems to suggest a conflation of feelings of authentic eye contact and knowledge that this was a video on a screen and the headset covered the participant’s eyes. In other words, the dancer did not know what the participant was looking at, and the participant felt this allowed them to look where they wanted to, even while still feeling that the connection of eye contact was happening. This points to simultaneous acknowledgement of mediated and unmediated feelings.

Regarding eye contact in reference to wearing headset that covers eyes, from participant self-report, it appears that eyes still function in the same way even with HMD present. However, as mentioned before this could be confirmed or refuted by an experiment using gaze tracking. The major phenomena that appears to be happening here is an experience of “un-mediating the mediated.” When participants sense and respond to mutual eye contact, the concept of “phenomenal transparency” (used in philosophy/psychology/cognitive science) could be applied, meaning that the physical headset has been rendered metaphorically “transparent” or forgotten about, as if it didn’t exist, and the participant and dancer could both see each other’s eyes.

Figure: Participant sees the dancer through the RealSense camera for the first time

Trust and Agency Through Direct Interaction : Embodied Interaction Influencing Trust

PI: How did you establish the trust with the dancer in the first place? Where did it come from?”
Participant 53: “It came from the fact that I had built up a certain sense of trust for the world so seeing a character in the world felt friendly. Like the fact that I felt trusting of the space that I was in - and I think probably to some degree the fact that I myself had been influencing the space that I was in felt like ‘oh this person’s in my space, they’re in my world.’ We talked earlier a little bit about eye contact, the fact that I really felt like they were looking at me was helpful.”

Trust and Touch

Figures: Participant interacts with dancer, seeing them through the camera and moving with dancer through touch.

Trust is both a cause for and effect of physical closeness via ongoing interaction (i.e. movement interactions between participant and dancer). From self-reported emotion data regarding trust as correlated to *Wake* journey event in which the participant and dancer were in physical contact with one another[88] combined with the

[88] See Findings, section 4.2.

phenomenological interviews and physical proximity data from the participant and dancer's trackers, two inferences regarding trust and touch can be made:

(1) Trust is necessary for physical engagement
(2) Ongoing mutual sensorimotor engagement can be used to foster greater trust

As a consequence of the ongoing, dynamical coordination of (1) and (2), trust and physical closeness form a dynamical system.

Trust, Touch, and Consent

PI: "Can you talk about trust in relationship to touch?"
Participant 53: "Yeah, I have to trust a person enough to want to put my hands into their hands. I don't touch hands with a lot of people. Holding hands with someone is a really specific and intimate thing. I don't know when the last time I touched hands with someone that wasn't my boyfriend was, unless I was high-fiving them or something like that. In order to touch another person's hands you have to have a trust built up for them. Some combination of the fact that I trusted everyone else, like I trust you and I know you're administering this. There's these two roles and then there's your absent role where I just know who you are. There was the facilitator's active role where I had learned to trust the facilitator very much. And there were layers of trust that I was then building on - it was definitely a conscious decision to touch - I think that was the biggest jump from me doing what other people were saying. There was also a jump when I started moving my body a little bit but it wasn't as pronounced I think as when I went for the touch.

PI: "So it was a conscious decision, you had to make that choice to do it?"

Participant 53: "I felt like since they said 'Can we touch,' I felt like I had the freedom to say no if I wanted to. It felt very consensual."

PI: "You chose to do it?"

Participant 53: "I chose to do it - I almost hesitated, but I was like let's just go for it."

Figures: Participant and Dancer explore movement together with real time camera feed (Intel RealSense) and touch.

5.2.5 Trust and Linked Emotions

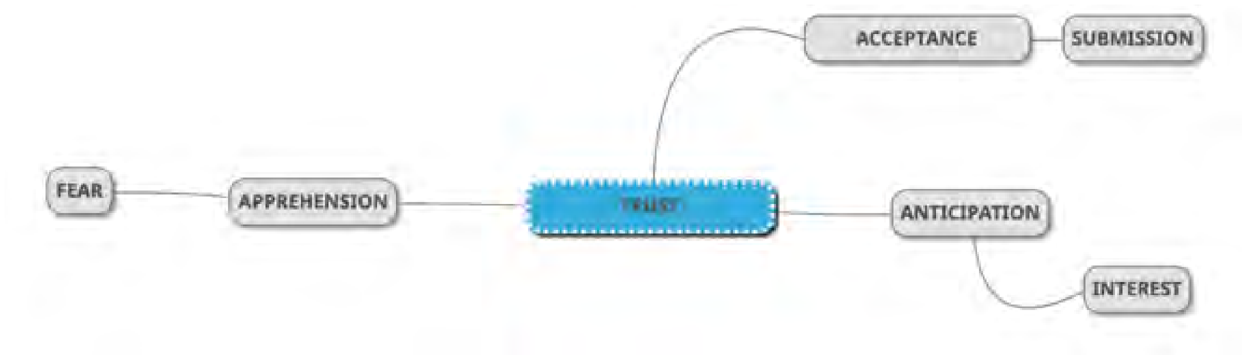


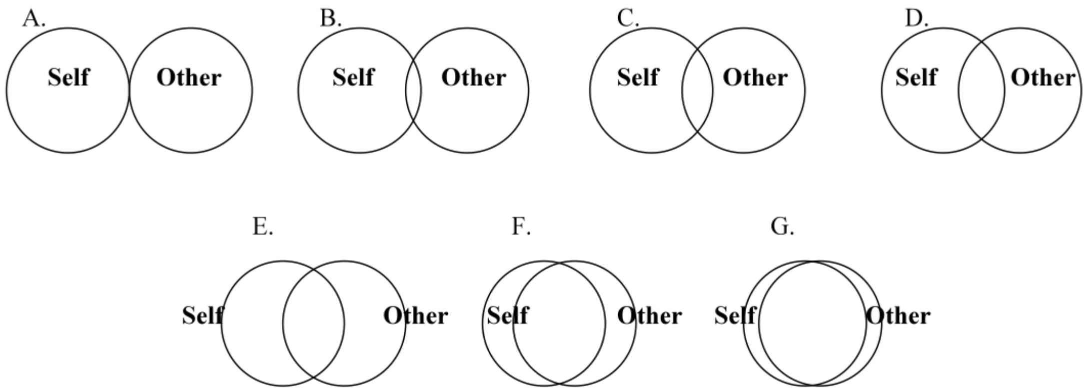
Figure: Concept Map for trust and linked emotions.

In the discussions with the participants, the emotions of acceptance, submission, anticipation, interest, fear, and apprehension were linked to trust, in the manner shown in the concept map above. One important criterion for trust is that the trustor can accept some level of risk or vulnerability (Becker 1996), as shown in the associated emotions which all were associated with an eventual shift towards, or simultaneous sensation of trust.

For Example: Trust and Submission

Participant 34: “I definitely felt a little submissive at times -especially with the hands - it makes total sense that submission is a mix of trust and apprehension because it was both of those things - ok I’m trusting you to touch our hands but now that this is happening I’m just going to submit to whatever you’re doing here. And similarly that I was in a more vulnerable position than the dancer was, being that they know what’s going on and also are inhabiting the real world, so I made a conscious decision to submit to whatever they were saying. It was submissive of me to be led around by the facilitator, it was submissive of me to do everything that she said with my body, so [conscious submission] was definitely a thing.”

5.2.6 Blurring of Body Boundaries & Relationship to Facilitator



In the Inclusion of Self in Other Scale, multiple participants reported a relationship to the facilitator as either A or G, when describing a similar phenomenon: the facilitator "disappearing" from consciousness during the experience. The association of A or G reveals that this same phenomenon can be conceptualized very differently:

Participant 85: "[My relationship to the facilitator] went to B when my tracker was not working - yeah we felt like a team - and then it disappeared from my consciousness, which could either be A or G depending on how you interpret it. G feels better because that makes the care feel more communal and kind and that I could get him back, like that kind of care, instead of a responsibility - but A it feels like a job or duty or responsibility."

Two participants reported the facilitator relationship moving from A at the beginning of the experience to F, a close overlap. They cited the same phenomenon for this increase in interpersonal closeness, in which the facilitator felt like "a voice inside my head."

When the facilitator "disappears from consciousness" or becomes a "voice in my head," the facilitator becomes an extension of the participant's body. The facilitator's voice merges with an internal voice, and the facilitator's actions serves to augment or replace the participant's own body parts (i.e. hands, eyes) which would otherwise be occupied with managing the hardware cables from the headset.

This blurring of body boundaries is described by N. Katherine Hayles as a projection of proprioceptive senses into simulated space, in this case between the participant's body and that of the facilitator. A similar phenomenon was described by participants regarding the tracked virtual objects attached to the Vive trackers worn on the wrists. Within the virtual environment, this augmentation of a physical body part performs what Hayles describes as a fluid intermingling of body boundaries with technological affordances, "so that they can feel the joystick [or other technological object] as an unconscious extension of the hand."[89] In *Wake*, the participant's body can be unconsciously blurred across multiple channels of sensation and relation between physical objects, virtual augmentations, and other people.

[89] Hayles, N. Katherine. "Flesh and metal: Reconfiguring the mindbody in virtual environments." *Configurations* 10.2 (2002): p.299.

Figures: Left: Facilitator guiding participant through space during Physical Orientation Exercises
Right: Facilitator takes care of twisted cable on participant headset during the experience

5.3 Design Implications

The discussion above has identified and discussed in detail the emergent themes and conceptual categories of the *Wake* experience, as examined within the user study. The content has demonstrated how specific design decisions and methods have contributed to or been reflected in the feelings and perceptions of the participants, especially as they have related to the concept of trust in ACLCPMR. For clarity aimed at designers working in XR, the discussion in this section will point to specific elements of the *Wake* experience, and formulate design implications interpreted from the user study. These key takeaways are aimed at helping designers and researchers decide how to approach the process of designing immersive experiences, rather than explicitly giving design methods as a rubric.

This section will be broken down into conceptual categories as follows:

1. Discovery
    a. Light and Darkness
2. Mastery
    a. Physical and Virtual Orientation Exercises
3. Social Presence
    a. Real Time Streaming Depth Camera
4. Onboarding and Offboarding

5.3.1 Discovery

Discovery is often the aim of the first elements a participant will encounter in an immersive experience. This sense of discovery builds interest, which, in *Wake*, was correlated with the design elements of darkness (A), the red spheres (F), and the participant's path revealed (N)[90]. Events A and F are encountered early in the experience, and N is the final design element encountered before the end of the experience. Discovery and interest impel a participant to explore further.

Before the participant puts on the headset, they are guided to discover a tangible material (kinetic sand), together with the facilitator. The participant plays with this material while wearing the Vive trackers on each of their wrists. These sensors are relatively small, attach with velcro straps, and do not significantly alter the senses (as the headset

[90] See Appendix for a list of *Wake* participant journey events.

does), and as such, they are a nominal first introduction to physically-worn hardware. The discovery and play with the kinetic sand encourages a shift in attention to a participant's sense of touch, which begins to re-orient the sense hierarchy and is designed as a transitional object to prepare the participant for wearing the headset, and the darkness (aka no imagery, blackness in headset) they will encounter therein.

The darkness (A) sets the stage for an environment to be revealed by light. This is a technique used in theatre and cinema, and is a commonly understood media/narrative trope. The introduction of the first volumetric light (D), correlated with anticipation, signals to the participant that either something will appear within that light, or they should move towards the light for the next element to be revealed to them. The interaction with the first red sphere (F) triggers a visual response in the form of a glow within the sphere, and the ejection of a small yellow sphere which moves outwards and triggers a light in the virtual environment, further adding to the participant's discovery of their abilities and location within this virtual space.

Eventually, the participant will illuminate the environment entirely, allowing them to see the whole space, which is revealed to be a highly realistic, to-scale model of the actual physical room in which the experience is taking place. This moment of discovery was described by multiple participants as a comfort (i.e. they recognized the space, felt familiarity and safety within it), and also associated with a sensation that they were "seeing through the headset" or that their "eyes were adjusting to the darkness." These responses indicate a successful, natural interaction in a virtual environment that mimicked the real world and physiological, perceptual experiences within it, augmented by layered virtual content that would not be possible in physical reality. This is one of the ways in which *Wake* created a hybrid mediated environment, and points to the potential for site-specific mixed reality experiences.

By introducing new elements during the course of the experience, this process of discovery continues throughout, which helps maintain the attention and motivation of the participant to continue. However, if the new elements are introduced too quickly, or without adequate interaction which provides meaning to the elements, the participant can easily become overwhelmed. This is due to the high cognitive load required to process this new information within the already physiologically and cognitively challenging scenario in which head-mounted, walkable XR experiences are implicated. Discovery in *Wake* is strategically designed to help the participant understand the context of their new (changing) surroundings through active engagement.

By developing a juxtaposition between familiar and foreign things, discovery can build to mastery, and participant interest is sustained. In *Wake*, this was articulated in multiple ways:

1. Merging of the particle system controlled by the dancer, visible before the camera was activated, to the real time rendering of the dancer using the camera, overlaid on this particle system.
2. Experience of Kinetic Sand at beginning, during the Physical Orientation Exercises and the sandbox interacted with when the participant is in headset.
3. Physical presence of dancer juxtaposed with mediated version of dancer rendered in real time in the headset.

5.3.2 Mastery

Mastery implies a learning process, and an increase in competency with a skill or action. Mastery is earned through repetition. After the initial discovery, a participant can gain a sense of ownership or agency over a situation through repeated or sustained engagement with a task that shows clear results indicating "success." This helps a user to define and understand an experience, to provide order within chaos. This process of mastery helps induce a flow state within the experience.

In *Wake*, the participant is verbally guided by the facilitator through two different types of what we describe as "orientation exercises." These are designed to help the participant gain facility with the physical and visual tools they will use later in the experience. The Physical Orientation Exercises (B), which are conducted while the participant sees darkness in the headset, consist of breathing, sensory awareness, and simple directed movements. When enacted by a participant, these actions help them to feel proficiency over their own bodily proprioception and physical safety, and help the participant to trust the facilitator, both of which can help enable the participant to move through the experience with comfort and receptivity. The Physical Orientation Exercises were the most common journey event correlated with trust.

Transitioning seamlessly from these to the Virtual Orientation Exercises (C), the participant sees virtual objects (translucent white rocks) which correspond to their tracked wrist movements (wearing the Vive trackers), and a green "rope" between the two rocks. The participant is instructed to "play" with these virtual objects, by moving their arms and witnessing the interaction of the rope, which moves dynamically and with real-world physics. Additionally, the participant will encounter three red spheres (F-H), which appear one at a time at about mid-height, to which the participant is connected via the same green dynamic rope encountered earlier. These spheres respond to interaction in a similar manner. Here, repetition contributes to the sense of mastery.[91]

Through sustained interaction, the participant can feel "mastery" over these virtual tools and physical movements, which can provide motivation, positive feelings, and fluency with the subsequent parts of the experience. Importantly, the real-world dynamics of the rope, and the height at which the spheres appear (generally at a level where participants can look straight ahead, not up or down), help to create intuitive physical interactions in virtual space. Many discussions of virtual interaction design articulate the high importance of dynamic, responsive movement which believably corresponds and contributes to the bodily sensations and movements of a participant. Mastery of the virtual environment helps to establish trust, and once this is achieved (i.e. once the participant has encountered and influenced the virtual environment), the subsequent introduction of a co-present person is more 'friendly' or more openly received by the participant.

The majority of currently available literature on virtual interaction design strategies is based on video game tropes, and an assumption that the virtual experience is a game in the first place. Alternative design strategies or simulation methods for creating different types of experiences are underexplored. Wake, by necessity, implemented design methods which challenged expectations of fast game-like pacing through slower interactions. The experience utilized a mixture of participant-triggered interactions and operator-cued "events" in a manner similar to that of a theatrical experience or interactive dance performance, and utilized cinematic strategies such as fades and a real-time camera feed.

5.3.3 Social Presence

A strong sense of presence in an XR experience can be gained through authentic social interactions, graphical and audio fidelity, and user agency to affect the virtual environment.[92] Social presence in *Wake* is mostly engendered by the same phenomenon within the experience: the appearance of the dancer. As discussed in earlier sections specifically regarding eye contact, it has been demonstrated that the sensation of mutual eye contact was a crucial element in participant trust and engagement with the dancer. The process of moving physically towards each other, becoming close enough to physically touch, and then engaging in improvisational movement is a significant act of empathy and connection on the part of the dancer and facilitator, and thus it is a social experience. This interpersonal

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[91] See section 3.4.5 *Interaction Design*, and *Appendix: Narrative of Wake Project Development*, specifically the section titled "The Path & the Tether" for an extended discussion of these interaction design elements, including previous prototypes.
[92] Adapted from Lombard, et. al. cited in Tham, et. al.

negotiation requires them to be very attentive and empathetic to the differing, and changing needs and responses from participant to participant.

Visually representing others in co-present VR experiences can be done in many ways, but the vast majority of these involve avatars (i.e. a human-controlled, computer generated representation of a person or character). Representing a unique individual with a high level of photographic realism is currently a critical question. Recent developments in 3D modeling and scanning (i.e. photogrammetry) have made highly detailed renderings and photographically-based captures of individuals possible; yet a 3D scan is simply a static, unmoving mesh, and even the most advanced, rigged 3D model of a human still confronts the "uncanny valley," or the repulsion experienced when faced with a humanoid representation which is *almost-but-not-quite real,* or *strangely familiar*.[93] A 3D scan of a person may thus be *photographically realistic*, but unless the scan can *behave realistically*, its embodied expression will not convey "aliveness," feelings, or intent in a manner that is intuitive or realistic. Put differently, real-time, intuitive, social communication between people within immersive media is enabled when participants can see, hear, and respond to others in a believable and instantaneous manner.

This brings social presence in VR to the question of telepresence. By developing a method to live stream a depth video of the dancer using the Intel RealSense, *Wake* sidesteps the questions of photographic and behavioral realism from avatars. Due to the dancer being co-located with the participant, social connection is enhanced through the ability to physically engage with each other through touch. In *Wake*, this occurred primarily through the participant and dancer's hands touching, as they engaged in simple improvised movement together.

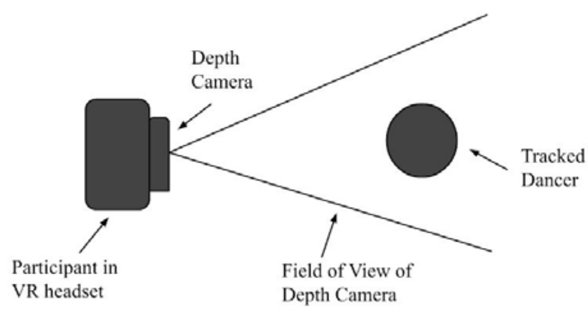

Figure: Co-located Co-Presence in *Wake*: This diagram represents the hardware system and co-presence structure used in *Wake* for rendering the co-located dancer. The dancer is rendered in real time through the Intel RealSense camera. The dancer and participant are tracked using Vive trackers, and can interact with virtual and physical objects together.

Qualitative findings from the semi-structured phenomenological interviews revealed that a vast majority of the participants (24 out of 25) felt that they were able to make and hold eye contact with the dancer as though it was real and mutual, despite knowing that the dancer was not able to see their eyes (because of the headset). The findings in *Wake* therefore plausibly suggest that real-world, genuine social interactions are possible within hybrid media environments like head-mounted VR/MR. More importantly, they suggest that ACLCPMR not only stands as a viable method for achieving experiential optimization when it comes to representing others in VR, but also for testing, researching, and developing new forms of human-machine mediated communication.

[93] Reichardt, J. (1978). Robots: Fact, fiction, and prediction. (pp. 166). London: Thames and Hudson.

5.3.3 Onboarding and Offboarding

For a longer discussion of these topics, especially regarding the design implications for trust, please refer to Section 5.2.1.3.

The experience begins long before the headset arrives on the participant's head, and reaches a critical juncture when the participant's body, and personal space is implicated as the physical hardware blinds them and restricts their movements (as in headsets with wires / cords, or with the visual "chaperone" system). Onboarding refers to the process of introducing a participant to a headset experience, and should be carefully considered in experience design, as it will impact the participant's ability to fully immerse themselves in the content once the are in-headset. Things to consider in onboarding are: what is the physical environment in which the headset experience will be taking place? Is this an installation with a full physical set design? Who will the participant interact with when they are introduced to the headset? How will the headset be fitted to the participant? What instructions will be given, verbal or otherwise? What is the first thing the participant will see in-headset?

In *Wake*, Physical Orientation Exercises (POV's) and Virtual Orientation Exercises (VOE's) were developed in order to facilitate a smooth transition from outside the headset to adjusting to the reality inside the headset. These are discussed in detail in section 3.5.3 on Interaction Design.

Offboarding refers to the process at the end of an XR experience, in which the participant readjusts to the world around them after the headset is removed. As with the onboarding process beginning before the headset is worn, the experience does not end abruptly when the headset is taken off. Due to the high cognitive load encountered in immersive experiences such as these, a participant will need a period of re-acclimatization to the environment and sensory stimuli around them. Often this means that they will need a place to sit or contemplate the experience, and the design of this place or scenario will impact the way the XR experience is received as a whole. Suggestions for this include a quiet place to reflect, a physical form of reflection such as a guestbook or other mode for the participant to express their thoughts, or a place to discuss with other participants.

6. Looking Forward

6.1 Limitations

6.1.1 Separation of Variables in User Study

A more traditional series of experiments could be conducted where the variables were more clearly separated out. Also larger participant size would reveal more clear trends.

Elements which could be examined:

- Shared virtual and physical objects
- Co-present person represented as abstract vs realistic
- Specific scenarios targeting specific emotions
- Cognitive spatial navigation and memory

6.1.2 Symmetric vs. Asymmetric Co-Presence

This project is an "asymmetric" co-present mixed reality experience, due to the fact that only one person was wearing a headset at a time. The dancer was co-present through their tracked movements using the same trackers as the participant wore, and through a real-time video stream captured by the Intel RealSense depth camera. The decision to not have the dancer wear a headset was made to test the effects of an unobscured co-present person encountered within the headset. Because the human face conveys so much information, especially through eye contact, and because from a technical research perspective, the pursuit of individual photographically real avatars generated in real-time i.e. "real-time streaming 3D avatar" is already happening[94], I chose to create that effect because this could apply to multiple scenarios - co-located immersive media in choreographed performance/entertainment experiences, and a possible future scenario where multiple users are wearing head-mounted devices but are rendered and perceived in real-time without the headset.

6.1.3 Tracking the Facilitator's Role

The facilitator role was not tracked throughout the experience - in terms of data collection - but this role could add another dimension to the understanding of co-location in terms of the "choreography" the facilitator had to do throughout the headset experience, keeping track of the cables, making sure the participant was safe - they are doing a lot of negotiating of space and co-located parties in terms of communicating with the technician who is running the experience on the computer, the dancer, and a kind of "enmeshment" with the participant in terms of almost functioning like an extra appendage or extension of the participant's body. Now that I am analyzing proximity data between the participant and dancer, I would have liked to do the same for the facilitator - which may have provided more insight into the discussion of the Inclusion of Self in Other (ISoIO) Scale in relationship to the facilitator.

6.1.4 Discussion of Distrust and Limitations of Standardized Metrics

While the Emotional Wheel metric used in the study presented "trust" as one of the 32 options, it did not include an option to choose "distrust." Therefore, this may have affected the data in terms of a discussion of trust.

In utilizing the Emotional Wheel and the IoSiO Scale, I chose standardized metrics that I judged to be the best way to gather quantitative data on what is otherwise complex, subjective, "slippery" qualitative experiences. These scales have been used in other HCI studies, and are generally accepted standards. But the shortcomings and biases of these instruments show us that more interdisciplinary work needs to be done between those in the social sciences, design and the arts, and computer science and engineering. Both the Emotional Wheel and the IoSiO Scale are imperfect, imprecise, and by their specific perspective, affect the data.

6.1.5 Limitations of Proxemics Framework and Analysis

The "Proxemics Over Time" visualization should not be taken to signify a complete understanding of the negotiation of interpersonal space between participant and dancer. There are many other factors which could have affected this interpretation, such as thresholding of the data, or tracker error. Because the other presence in the virtual environment was a co-located, realistically represented dancer, and not a computer generated avatar or object with predictable, repeatable, or rule-based movements, there is a general difficulty in precisely identifying what

[94] https://www.wired.com/story/facebook-oculus-codec-avatars-vr/, Accessed March 14, 2019.

caused the participant-to-dancer proximity to be thusly expressed. Bailenson, et. al.[95] has studied proximity in virtual environments using humanoid virtual agents (computer controlled) and avatars (person controlled) and abstract shapes. His contributions show user interpretation of virtually created presences which align with the study of personal space done by Argyle and Dean (Equilibrium Theory, 1965). In Bailenson's experiments, proxemics can be more precisely measured due to repeatability of the avatar movements. However, this study lacks the ability to examine an authentic, real-time human-to-human interaction and interpersonal negotiation that can only be achieved through the presence of another live human being, mediated or not.

Regarding proxemics measurements, there are many differing cultural and personal expectations of interpersonal space / proximity. The measurements used in the *Wake* study will not apply to everyone, based on culture or personal experience (i.e. person from another country where personal space is conceptualized differently, or nurse whose relationship to personal space is much different because she is in intimate contact with many people's bodies on a daily basis, or personal experience with abuse or violation of personal/intimate space).

6.1.6 Limitations Regarding Other Channels of Mixed Reality

Wake mixes reality mainly on the visual channel of virtuality and mixed reality. It is still occular-centric virtuality/mixed reality in terms of the sense that is being focused on that is being mixed. In Western thought, seeing is the most privileged sense, and the one associated with the construction of truth and existence.[96]

Other channels within the world of virtuality / mixed reality that were not addressed in this project, aka the sound was real speaking, the soundtrack was played on speakers in the room, the tangibility of the sand and other person was real and physical - i.e. there was no electro-magnetic stimulation glove, there was no augmentation or changing of voice, aka a co-located person speaking into a microphone and then their voice being audio tuned to a chipmunk sound, etc. We did attempt this in the first prototype where the voice was recorded and over time in the experience the voice would slowly go from robotic to real and then the voice would be spoken live by the co-located person. So this was considered, but it was not implemented in the final version of the piece which was used in the study. Future research could investigate virtually augmenting senses other than vision.

6.2 Future Work

6.2.1 Further Research

6.2.1.1 Proxemics and Eye Contact

Future work on this data: further analysis of participant self-reported mutual eye contact, correlated with observed participant gaze (i.e. when participant gaze meets dancer gaze as represented in the camera feed) using the in-headset recording, correlated with interpersonal distance, and observed level of movement mimicry between participant and dancer. Further work would include developing a method to analyze movement mimicry in a standardized, or measurable way. How quickly did participant and dancer movement become symmetrical, how long did it remain this way, and are there perceptible shifts in who was leading this movement?

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[95] Bailenson, Jeremy N., et al. "Interpersonal distance in immersive virtual environments." *Personality and Social Psychology Bulletin* 29.7 (2003): 819-833.
[96] Hawaway 1988, Dyson 2009.

Further research should involve the development of experimental scenarios which limit the variables involved, in order to reduce potential conflation errors or conflicting data, as well as a standardized method for comparing quantitative data to phenomenological qualitative data. Additionally, the role of social psychology in XR research should be re-assessed, especially regarding an updated understanding of the work done by Edward T. Hall and Argyle & Dean, in relationship to shifting and current societal expectations, rules, and re-negotiations of personal space, eye contact and other nonverbal communication, and gender expression.

6.2.1.2 Symmetric Co-Presence

In this experience, the co-presence is not equally balanced because one person is in a headset and the other person is not - and the other person is a performer. This is an asymmetric experience. Further work could create a study based on two people who were co-present in headset and co-located. However, the scenario described in this thesis could also describe what may become a common scenario, whether this is a staged, location-based performance experience, as is already common in theme parks, live events, and immersive theatre scenarios. Or, an ACLCPMR experience could also describe an experience in a workplace or home environment in which multiple co-located people are communicating, yet some are wearing a head-mounted device, and the others are not. We see this scenario already being explored with Microsoft's "Flashlight" feature in their Windows Mixed Reality headsets.[97] Additionally, symmetric co-presence scenarios are being attempted utilizing facial motion technology, scanning, and other research being done by Oculus/Facebook Reality Labs[98] in which the headset is digitally removed as if it didn't exist, and replaced with a highly accurate avatar of each individual user - though whether these avatars will still pass the "uncanny valley" test remains to be determined. At present, ACLCPMR, particularly the scenario used in *Wake*, utilizes real-time streaming of volumetric video in order for participants to respond to the real, unaltered facial expressions of a co-present person.

6.2.2 Why Examine Embodiment, Affect, & XR? What We Can Do Now:

Evolutions in technology contribute to shifts in communication and our relationship to the physical world. Media technologies in particular, of which head-mounted XR experiences are a particularly prescient example, contribute to a ritualization of communication, initially defined by those who create the hardware, content, and experiences (XR creators, designers, engineers, and researchers), and re-negotiated by the resultant users. As media theorist Vivian Sobchack articulates, "Each technology not only different *mediates* our figurations of bodily existence, but also *constitutes* them. That is, each offers our lived bodies radically different ways of 'being-in-the-world'... Each differently and objectively alters our subjectivity, while each invites our complicity in formulating space, time, and bodily investment."[99]

Head-mounted XR, by its immersive nature, reorients our relationship to physical and spatial realities and paradigms. Within this re-oriented scenario, the necessary negotiation of cognitive processes and interpersonal communication contributes to the creation, maintenance, and transformation of societal and embodied experience. As Dourish[100] discusses, tech is co-evolutionary with us. It fundamentally alters our lives, as we can see from the past 100 years, and has vastly sped up given the introduction of the internet and mobile devices. And Hayles[101] states, "[l]iving in a technologically engineered and information-rich environment brings with it associated shifts in habits, postures, enactments, perceptions," which highlight and bring about changes in culture, biases, and relations.

[97] https://uploadvr.com/microsoft-mixed-reality-flashlight/, Accessed July 28, 2018.
[98] https://www.wired.com/story/facebook-oculus-codec-avatars-vr/, Accessed March 13, 2019.
[99] Sobchack, Vivian. *Carnal thoughts: Embodiment and moving image culture*. Univ of California Press, 2004. pp. 136-7. Emphasis in original.
[100] Dourish, Paul. *Where the Action Is? The Foundations of Embodied Interaction*, 2001.
[101] Hayles, Katherine N.

As Bailenson[102] and others anticipate, head-mounted XR technologies are poised to accelerate their transition from laboratories to homes, workplaces, and location-based themed entertainment. Our increasingly information-rich encounters with daily life, enmeshed with our perceiving bodies, should not be left to the whims and imaginations of an industry with a demonstrably limited perspective.

As we have discussed in this thesis, head-mounted XR is an intrinsically embodied, and therefore affective, medium. It has the potential to be a technology of isolation, violence, and objectification. However, it also has the potential to be the opposite, and this can be achieved through intention and consideration of the topics described here. *Wake* is an examination of a relationally consequential form of XR, in which a mediated experience must be negotiated between parties with differing perspectives. ACLCPMR asks us to re-orient ourselves within an intersection of physical, virtual, and social realities, and negotiate a new form of communication. Cross-disciplinary research in the ever-shifting realm of social psychology, which has already been implicated with virtual reality as a method for conducting empirical studies concerning human social behavior[103], should investigate co-present XR as a social scenario in and of itself, in a way similar to the emergence of innovations in telepresence, social media, and other forms of technology-enabled communication.

From an embodied, phenomenological perspective, queer theorist Sara Ahmed explains, “emotions shape the very surfaces of bodies, which take shape through the repetition of actions over time, as well as through orientations towards and away from others. Indeed, attending to emotions might show us how all actions are reactions, in the sense that what we do is shaped by the contact we have with others.”[104]

Given these considerations:
1. That we all have a body and we do not leave this body when we put on an XR headset;
2. That, as interdependent, relational beings, trust is a fundamental part of being human;
3. That perceptual processes and emotional experiences are intertwined[105];

We can research and validate design choices and experiential strategies through examining issues of:

1. interpersonal space
2. embodied communication
3. sensory perception
4. emotional phenomena
   within ACLCPMR

We can use the intimate, sensation-heightening qualities of head-mounted immersive experiences to be consciously embodied within ourselves. Using this renewed attentiveness, we can connect to and share experiences with others, while benefiting from the expansive possibilities made manifest through immersive technology. We can design for actively trusting, socially mindful, and intentionally embodied interactions which lead to transformative, powerful experiences in immersive media.

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[102] Bailenson, Jeremy. *Experience on Demand.* 2018.
[103] i.e. Bailenson, Blascovich et. al. 2001, 2005.
[104] Ahmed, Sara. *The Cultural Politics of Emotion*. Second Edition, Routledge, 2014. p. 5.
[105] Zadra, Jonathan R., and Gerald L. Clore. "Emotion and perception: The role of affective information." *Wiley interdisciplinary reviews: cognitive science* 2.6 (2011): 676-685.

Appendixes.

1. Phenomenological Semi-Structured Interview Questions
2. Extended Project Narrative

Appendix 1: Semi-Structured Phenomenological Interview Questions

Wake Post-Experience Interview Questions

Semi-Structured Format

These are open-ended questions with possible follow up questions, based on the answers of the participants. All questions and discussion are spoken, in conversation between the PI (Anna Henson) and participant.

There are 4 sections in the interview, which may not follow this order, but will all be asked:
1. Bodily Sensations
2. Emotional Experience
3. Relationship to the Dancer / Facilitator
4. Interaction and Spatial Design

<u>BODILY SENSATIONS</u>

1. First, I want to try to understand how your body is feeling directly following the experience. What physical sensations are you feeling in your body right now?

2. Thinking back through your experience, what physical sensation(s) can you remember from the experience?

3. Pick 5 words to describe your physical body's sensations during the experience. Can you pinpoint moments in the experience that you felt each of these sensations?

<u>EMOTIONAL EXPERIENCE</u>

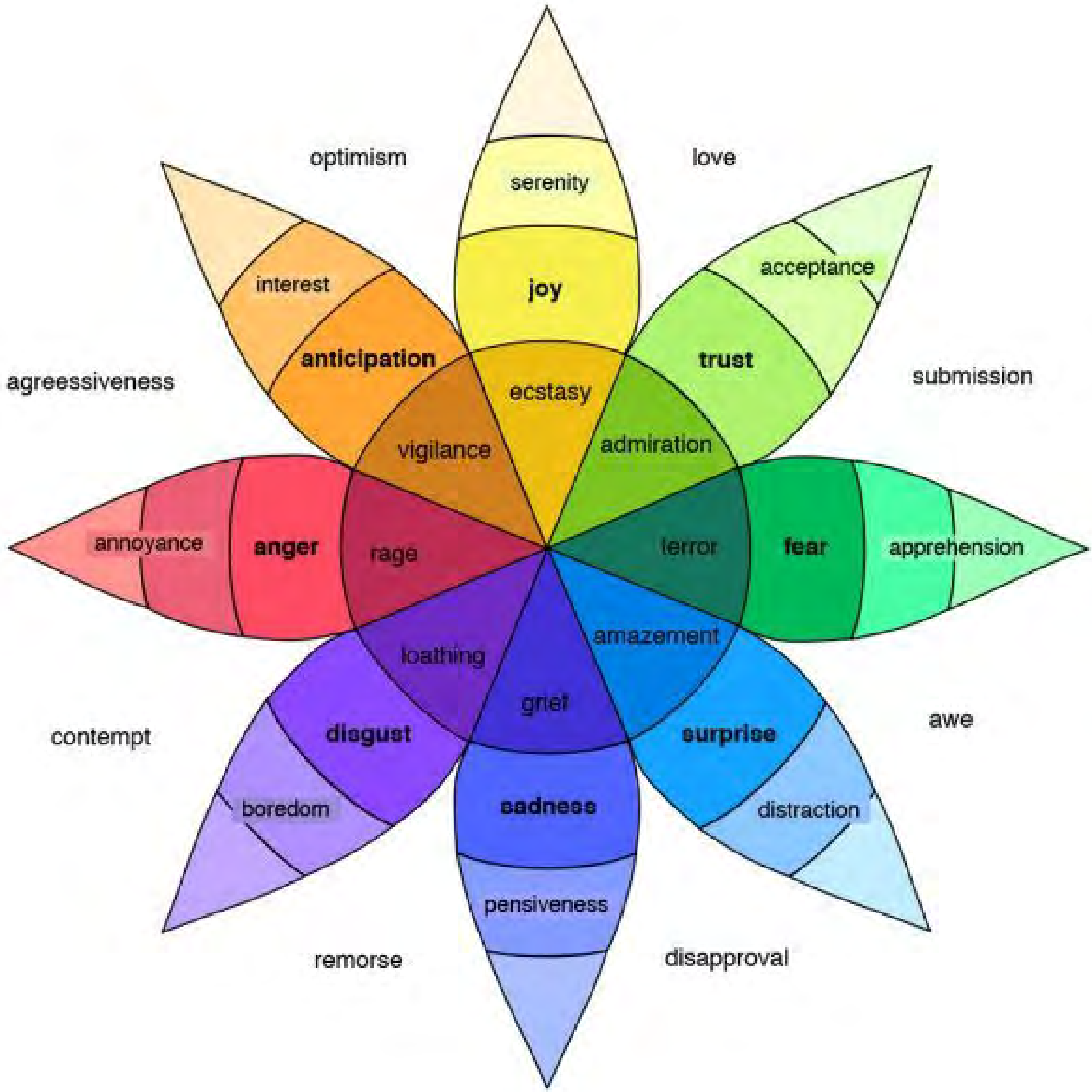
1. Tell me about your journey.

    a. How did you feel during the experience?

2. The Emotional Wheel:
   Let's take a look at this visualization of emotions. This shows eight categories of related emotions, with increasing levels of intensity from outermost to the innermost ring. The emotions written in between the colored sections are a combination of the two colors on either side of it.

   I'd like you to look over this image, and pick 5 emotions that you felt during your experience.

   Next, can you pinpoint the moments in the experience that you felt each of these emotions?



Robert Plutchik's Wheel of Emotions, 1980

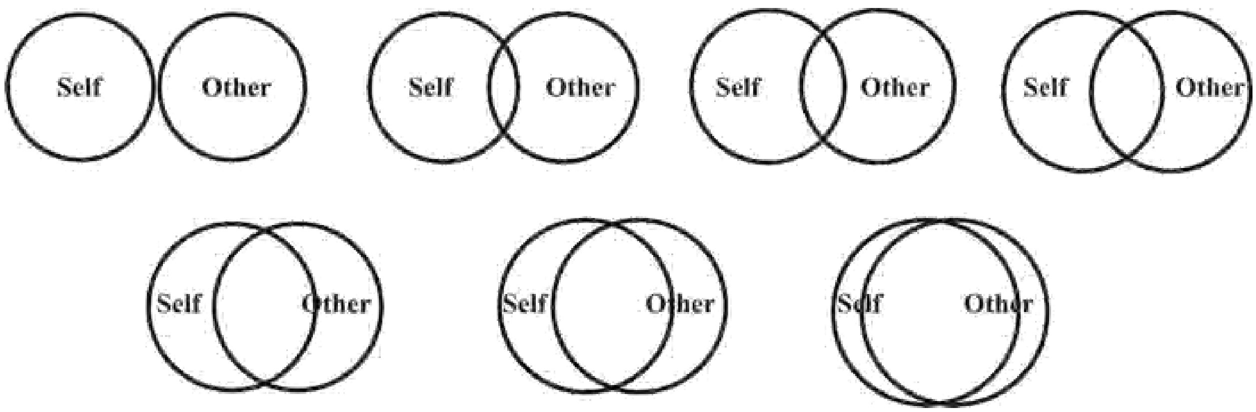
<u>RELATIONSHIP TO DANCER AND FACILITATOR</u>

[Inclusion of Self in Other Scale, Aron, A., Aron E. N., & Smollan, D. (1992)]

1. I would like you to please point to the picture below that best describes your relationship to the facilitator.

2. Next, please point to the picture below that best describes your relationship to the dancer at the beginning of the experience.

3. What about at the end?



4. How did the dancer communicate with you during the experience?

5. How did you communicate with the dancer while wearing the headset?

6. What was it like when you saw the dancer?

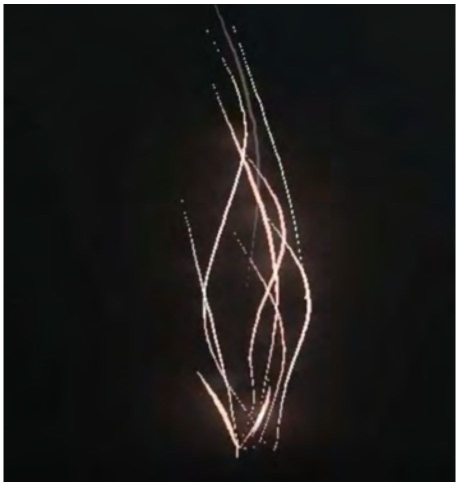
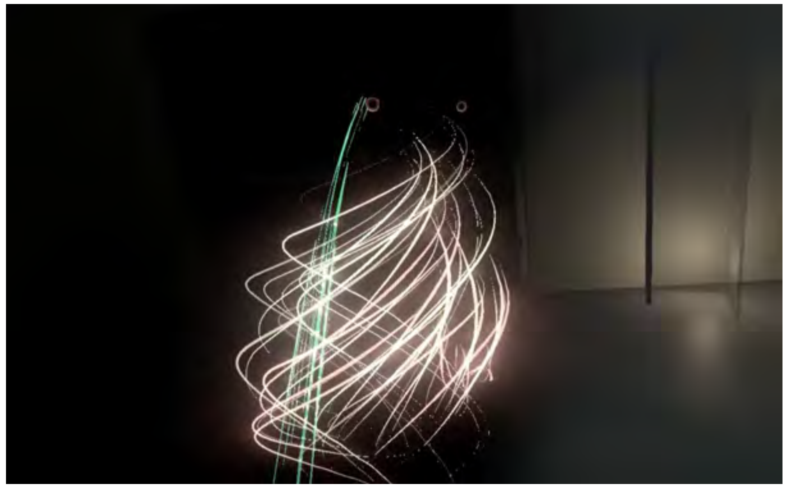
INTERACTION DESIGN

1. There were two experiences with sand. One before the headset, and one with the headset. Can you tell me if the first sand experience had any impact that you noticed on your body, feelings, or attention? What about the experience of the second, in the headset?

2. How did you navigate the virtual environment?

    2a. What parts of your body did you use to navigate through the virtual environment?

2. What is this?

3. Who else^ were you aware of?
^To be asked if participant answers that the particle system was related to the dancer.

SPATIAL EXPERIENCE

4. How did you feel in the virtual space?

5. What did you notice about the virtual space?

6. What about the physical space?

7. Tell me about your path.

Appendix 2: Narrative of *Wake* Project Development: Previous Prototypes

First Prototype

The Camera Feed

The first priority of the creation of *Wake* was to get a real-time, high fidelity stream of the Intel RealSense camera running at an acceptable frame rate for VR (90fps). The technical discussion of how this was achieved is articulated in the Methods chapter. I had worked with varying ways of representing dancers' bodies in VR in previous projects (Body, My Body), using abstract avatars, 3D scanned realistic representations of dancers rigged to marker-based motion capture data, and volumetric point cloud capture, which had provided the closest to lens-based (photography or video) representation of the dancers. However, none of these were able to be captured and rendered in real-time. In this project, I wanted to explore the effects of a co-located dancer streamed in real-time to a headset, represented as realistically as possible. This would allow for improvisation between the dancer and participant, and communication through physical movement and facial expressions, as well as the possibility for spoken communication and touch in combination with the visually mediated representation of the dancer in the virtual environment.

In the early stages of the project, the Intel RealSense camera was newly available. This camera was just the right size to fit on the front of a VR headset, as the other option, a Microsoft Kinect, was far too large. It was important that the camera be placed at the position of the participant's eyes in the headset because I wanted the view of the dancer to come from the first-person perspective of the participant. The limitation with the RealSense is the field of view. As is clear in the documentation from the headset, the Intel RealSense d415 camera has a limited field of view, therefore the dancer's body could only be represented in part, unless the dancer was significantly far away from the participant. This was found in the user study to give the effect of a kind of telepresence, reminiscent of video chat, within an otherwise fully immersive environment. Some participants found this distracting, and ideally I would have liked to have had the full body visible at all times. However, other participants found interesting ways to negotiate this limitation, calling it a "window" that they could control by moving their head to reveal different areas of the camera feed. Observing how and when the participants looked at the dancer's face versus their hands was interesting to understand what element of body language was providing the needed information for communication between a participant in-headset and a co-located dancer. Further research could examine this question using gaze tracking.

Intel RealSense D415 Depth Camera

The Environment

In thinking about the design of the virtual space, I originally wanted to create what could seem like a contradiction: a featureless environment with features. Rather than a detailed environment, I was primarily concerned with designing an interaction for a participant to move along a predetermined path and encounter a person about halfway down that path. This experience was mostly about simple movement and the presence of another person. I didn't want the environment to convey specific narrative information or to distract or confuse the participant, but it did need to provide simple spatial structure to encourage the intended exploration.

In the first prototype, I did not use darkness to control movement as I had in my earlier projects. I created an open, light environment, with organic, simple features in the form of white rocks. I wanted to avoid science fiction tropes and colors, and create an environment that mimicked a minimal natural world.

Image: Prototype 1: “Pink Desert” environment, translucent white rock formations, depth filtered RealSense camera feed of dancer (Ru Emmons). On the left, in the Unity Game Window, the entire path is visible, with speaker icons at the “waypoints” where the participant would stop and receive an audio instruction before moving forward.

The Path & the Tether :
Searching For Natural Interactions for Room-Scale VR Without Controllers

I created a series of “waypoints” along a pre-determined path created by a bezier curve in Unity. This path was located on the floor of the environment, aligned with the floor of the physical room in which the experience was happening. It was revealed to the participant one section at a time using a line renderer along the bezier curve. The participant wore a Vive tracker on one of their wrists, which formed a tracked point to attach another line render that connected dynamically to the static path on the floor. I called this line the “tether,” and it was used to help give the participant a sense of where they were in space and a guide for their movement. As the participant walked along the path, it disappeared behind them, analogous to the path being “eaten” by their movement. Pre-recorded audio instructions would play at each waypoint, guiding the participant where to go next, and what to look at or focus on, such as where they were connected, their breath, or the dancer in front of them when they were revealed.

The tether was a first pass at trying to find a natural interaction system to guide participants in movement through an environment without using traditional controllers. Design methods for room-scale VR have been formulated and examined by numerous companies who create content and hardware, and a general consensus is that having the ability to stand up and move your whole body, combined with accurate tracked inputs (whether full-hand tracking like the LeapMotion, a traditional control pad, or other device), are crucial elements of creating a sense of presence, or “being-there” that VR relies on.[106] However, many of the interaction design strategies that are widely disseminated are based on an assumption that the developer or designer is creating a game, often with tropes of video games such as throwing things, shooting, or knocking things down. This means that alternate types of design strategies for different types of experiences are widely underexplored. Wake attempted to address this gap through necessity to create a different type of experience.

We observed that the path navigation was not clear enough to most participants, who were often confused or missed the path entirely. Because of the length of the Vive headset cable and the distances of the lighthouses, the entire physical “journey” that the participants walked could only happen over the span of about 20 feet. We wanted the participants to feel as if they were taking a physical journey, but with a limited space, this meant the distances between the waypoints needed to be small. This further impacted the participants’ understanding of the path, as they would often take steps that were larger than the distance to the next waypoint, and so they would miss it. Also, when the environment was so open, and the only other moving element in the space is a far away line, it seems clear that the participant would want to walk directly towards this moving line. If they did so, they would miss multiple waypoints and possibly run into the dancer physically, before the camera feed was activated. In essence, with this design, we were giving the participant the wrong clues about what to do and where to go right from the beginning.

We learned that looking down in VR is not natural or comfortable, the headset is heavy and sometimes slips, and your peripheral vision is limited in VR, especially vertically.

The lighting was the same across the whole space, so there was no variation to help control focus or guide the user over time or spatially. Because of this, and because the path on the floor was difficult to see, we observed that people moved much too quickly and without direction. We observed that patience may be difficult to cultivate in VR, in terms of placing a user in a foreign environment and having the user wait for instructions or for an environment or interaction to slowly reveal itself. This means that the interaction design and experience flow must work towards this in subtle, but clear ways. The combination of pre-recorded audio instructions, with a head-mounted device, and an expectation of movement, was a challenging cognitive load for a participant to negotiate, often with an experience that was foreign to them if they were new to VR. This meant that a participant could feel vulnerable or confused easily.

The Movement Interactions with the Dancer

The movement interactions with the dancer worked generally very well. The RealSense frame rate was consistently around 90fps, so the dancer was rendered realistically in real-time. As shown in the following images, the participants engaged in exploratory full-bodied physical movement with the dancer, and the facilitator role certainly had their work cut out for them in maintaining the headset wires and keeping them untangled and out of the way of the participant as they moved through the space.

The dancer wore a Vive tracker on their wrist, which also rendered their own tether to a section of the bezier path on the floor. In the early part of the experience, the dancer was rendered only as a line across the virtual space from the participant, which moved dynamically with their wrist movement while staying tethered to the floor path. I chose to not reveal the camera feed until the participant had moved through three waypoints on their own, because I wanted to explore the process of a human presence appearing abstract and later realistic. As in Body, My Body, the dancer was first abstract, but Wake pushed this concept to add the camera feed. This was inspired, undoubtedly, by my

[106] https://www.youtube.com/watch?v=U8mku0JvuLI, Unite 2015, “The Holodeck is Here - Designing for Room-Scale VR,” Owlchemy Labs & Unity. Accessed December 6, 2018.

work with volumetric capture on an earlier project with slowdanger.

Image: In-headset view, participant's hands connecting to dancer, rendered by Intel RealSense

Images: Physical Movement with Participant, Dancer, and Facilitator

Creating a Ritual Through Shared Physical Objects in XR

We wanted to incorporate shared tangible objects into the experience, that would cross the boundary between the physical and virtual. This physical object was encountered twice in the experience, once with the facilitator, before the headset was put on, and again with the dancer, in-headset. The object served as a tangible material with which to first form a memory without the headset, and then recall it later in-headset, and to draw attention to tactile sensation for the participant. By using shared physical objects in XR, we can create tangible interactions with co-located, co-present people, and we can also use this object to create meaning as a transitional, or boundary object that exists at the intersection of physical and virtual worlds, just as the participant does within the mixed reality environment. I was interested in the participant's experience of a familiar material that could be easily intuitive and allow for direct interaction, so we chose Play-Doh. The participant was asked by the facilitator to squeeze the Play-Doh at the start of the experience, to "leave an impression." After the participant encountered the dancer in the headset, with the camera feed active, the dancer also presented the participant with the Play-Doh again, which was squeezed together between the dancer's and participant's hands. The participant negotiated a similar physical act in both an un-mediated and mediated situation. I was interested in exploring the effect one might have on the other, and the sense of connection that the participant might feel with the dancer and the object, as affected by the layer of mediation.

Image: Dancer and Participant interact with Play-Doh together, and connect through touch

Image: Play-Doh "Impressions" created by Participant and Dancer during Wake experience

A Note on Vulnerability in Head-Mounted XR

If the interaction design doesn't work, the tech glitches, or participants think they aren't doing something "right," this can engender a strong sense of vulnerability and for some people, even fear, while wearing the headset. This means that the design methods need to focus on creating interactions that allow natural discovery and use intuitive affordances and meaningful gestures to help guide the user through the experience. Also, every experience should make clear at the outset that the participant can stop at any time, and let the participant know if there is a gesture they can use to signal they want to stop, if they will need assistance removing any hardware. Head-mounted XR can trigger very real fears, phobias, or medical issues. This is why many XR experiences have a release form to sign before beginning the experience.

Overall, the first prototype was successful on a number of levels, and many participants responded with positive emotions, and an intimate sense of connection with the co-located dancer.

By observing participants across a spectrum of experiences, both positive and negative, I wanted to explore more in-depth how the various interaction methods, environment and experience design strategies contributed to the physiological and psychological responses of the participants within this ACLCPMR experience.

Second Prototype

Site Specificity

In the second prototype, we began to think about site specificity, integrating the structure and character of the physical space in which the experience was conducted into the virtual environment. The previous version situated the participant in a pink desert, which seemed too light, without structure, and resulted in people moving too quickly and without direction. For the second prototype, we would be installing the experience in a long hallway at the Carnegie Museum of Art in Pittsburgh, Pennsylvania. Here we decided to add more architectural structure within environment to guide and focus the participant, instead of leaving them in a large mostly empty space as we had in the first prototype. I was also interested in the question about memory of physical space before a headset was put on, and connecting that to the virtual environment. How, if at all, does this influence participant's confidence in navigating space? If the structures in the virtual environment do not look similar to the objects in the real world, but are placed in similar locations and at similar scales, does this still conjure a memory or association with the physical environment? These findings will be elaborated on in the following chapters. This design decision explored memory of the physical space and structural association with the architecture or environment in the headset. This is a factor that has been explored by cognitive scientists studying spatial memory[107], and could be separated out into an experimental study with XR in future research. In the second prototype this was done with similar spatial structure, rather than literal representation.

At Carnegie Museum of Art, the experience was installed in a hallway with a series of doors on one side, and low benches along the opposite wall. In the virtual environment, we created tall rectangular structures and positioned them in a similar place to the physical doorways in the hallway, and shorter rectangular structures opposite these, which reflected the size and position of the physical benches.

[107] King, John A., et al. "Human hippocampus and viewpoint dependence in spatial memory." *Hippocampus* 12.6 (2002): 811-820.

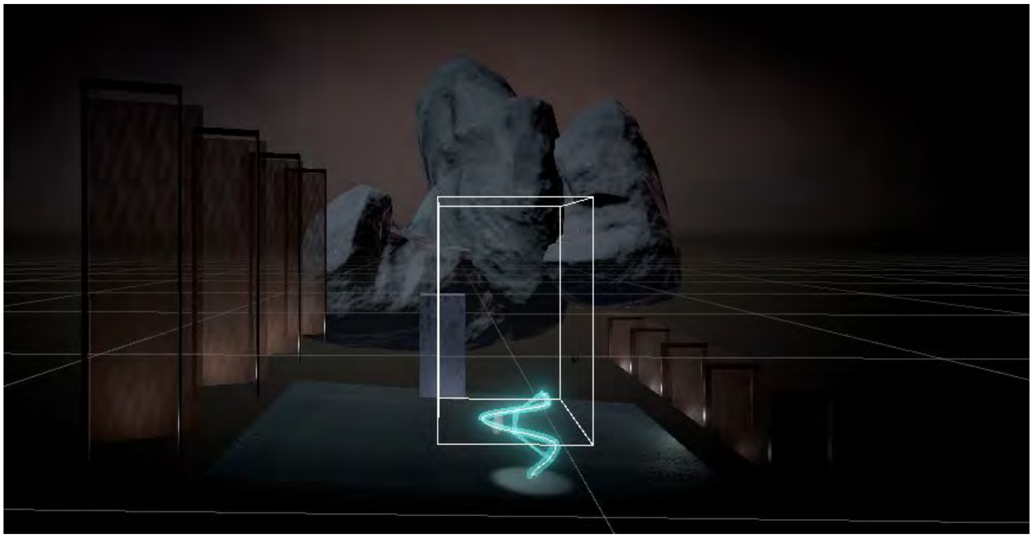


Image: Prototype 2, Hallway configuration, lighting is darker

Image: Prototype 2, Dancer with tracked line “tether” visible in headset

Spatial / Virtual Environment Design: Minimalist Sculpture and Installation Influences

In moving from a “featureless environment with features” to an abstracted representation of the real physical space, I looked to minimalist sculptors for abstraction and delineation of space. Two artists whose work was particularly influential are Donald Judd and James Turrell.

Image: Donald Judd, Marfa Texas. Image Credit: NPR

Image: James Turrell, Skyspaces: Arrowhead (2009)

Image: Hallway, Carnegie Museum of Art, location of Wake's second prototype

Controlling / Guiding Participant Movement and Pacing in the Virtual Environment

In the first prototype, the experience was designed for an open space, with a visible horizon. For the second prototype, we decided to make the virtual space similar to the real world space and added semi-transparent architecture structures to the scene. After we tested the second prototype, we observed that the participants were still moving at a fast pace and did not stop and listen to the audio instructions at each waypoint as we expected. Therefore, we sought a way to encourage the participant to move slower and stop at each waypoint.

Our first solution involved a semi-transparent barrier at each waypoint to keep participants from moving forward but still allowing them to see the dancer's presence in the form of a particle. However, we gained the feedback that participants would want to move around the wall instead of standing in the spot, which was referenced from one participant as related to video game mechanics of negotiating wall barriers.

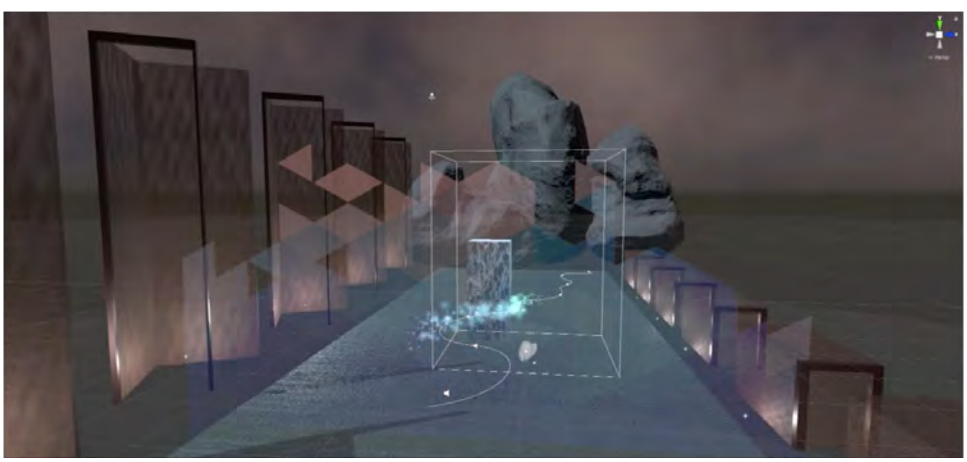


Image: Translucent barrier iteration with dancer particle visible

We then thought about using the environment to create a natural barrier which blends well with the atmosphere we wanted to create. After looking at examples such as volumetric fog in games like INSIDE, we decided to incorporate volumetric lighting into our experience as well. We used Hx Volumetric Lighting. At first, we wanted to keep the space open and use volumetric fog to block the player's way.

Our plan was that when the player is moving slowly, the volumetric fog would sparse out and show players the way. However, we ran into the issue with dynamic volumetric fog produces flickering artifacts when the fog is moving too fast. Even though temporal sampling and dithering are able to successfully reduce the effect on monitors, it is still noticeably visible in VR headset. To study and fix the program requires a deep delve into the Hx Volumetric Lighting package source code. Additionally, with volumetric fog the scene contains too much information for the player to perceive simultaneously. Considering both factors, we decided to abandon the idea of having volumetric fog as a barrier.

From our previous experiments in participant movement in VR, through *Body, My Body*, we returned to the concept of darkness. We created a minimal wall structure around the playable space. To avoid sensations of claustrophobia, we decided to have an open-ceiling with volumetric light shafts shining on the ground. In order to encourage players to move slowly, we programmed the lighting so that new lights would be added to the darkness as a reward for participants completing an interaction at each waypoint. Pre-configured lights would also gradually light up as the player walked through space, which transitioned the environment from complete darkness to well-lit space in a gradual, natural way. This lighting interaction was successful from a participant perspective; one participant questioned whether their eyes were adjusting to the darkness naturally as the space illuminated. This suggests a design choice that mimicked biological sensory processes, and therefore was subtle and believable.

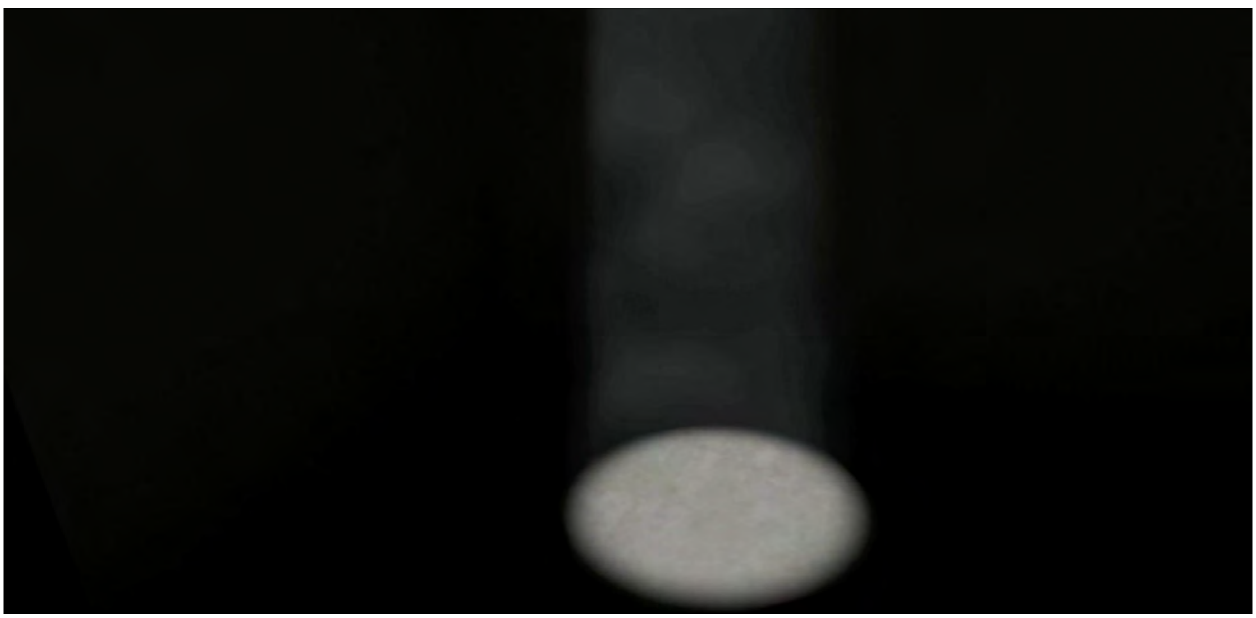
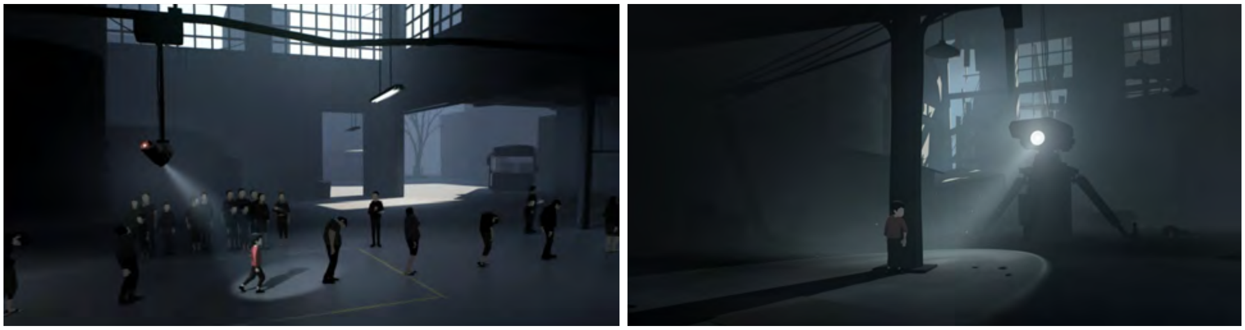


Image: Volumetric Light in *Wake*, from in-headset recording

The environment design in the second prototype was influenced by the look of the game “Inside” by Playdead[108]. This game used minimal industrial architecture, and strong volumetric or slanted lighting which conveyed a very good sense of environment and atmosphere.

[108] https://playdead.com/games/inside/, Accessed December 10, 2018.



Images: "Inside," by Playdead

Darkness as Metaphor and Navigation Tool

Darkness and abstract architectural environment with long hallway and volumetric lights can easily become "horror-esque" or convey, as an advisor put it, "a Druid ritual where I'm walking towards my execution." That certainly wasn't what we wanted, so when we chose to use a black skybox and sparse volumetric lighting, we had to negotiate how to accept enough of the feelings of anticipation and mood that darkness would naturally convey, but without the narrative sense of foreboding ritual.

Key question: How can darkness become a clear design tool to guide participant behavior?

As we had explored in "Body, My Body," having a flashlight of sorts, which illuminated the environment through interaction, was an effective tool for navigating darkness. This seems obvious as this tool is of clear use in the real world, but while creating a virtual environment inside a game engine, it can be difficult to find (or remember) the simple, real-world-equivalent solution in a software that seems to be made for spectacle, violence, or fantasy.

We learned through observation and testing that giving a participant an active ability to illuminate an environment is satisfying, and gave us the ability to begin in total abstraction and slowly bring a more realistic scenario into focus over the course of the experience. We refined this design strategy for the third Wake prototype, for the user study.

In the third prototype, we moved to a different physical location, and our conceptualization of site-specificity evolved with this move. The virtual environment changed significantly again, as we no longer had a long hallway to design for, but a relatively square box, which also changed the narrative associations. This will be discussed in more detail in the third prototype section.

Introduction of "XR Calisthenics" or Physical Orientation Exercises

Based on our observations and discussions with participants during the second prototype, it became clear that the participants would benefit from a more deliberate orientation to the headset, to feeling their sense of balance and movement while wearing the headset, and to walking around in space before the more choreographed part of the experience began. This would later become a clearly defined set of "Physical Orientation Exercises" in Wake Prototype 3, the user study version. Walking around in space helped the participant to know that there was nothing in the way, no physical objects they could bump into, so that they felt more safe and free to move around during the experience. An interesting insight here is that even though the participants saw the entire physical space in front of them when they arrived, before they put the headset on, this is not enough to trust that the space is clear *after* the headset is on. This means that there is a cognitive disconnect from un-mediated to mediated experience, where the headset truly functions like a blindfold and a sense of "permanence" of the physical environment, and trust in physical safety must be reclaimed and reassured. We addressed this through a set of short orientation exercises we called "XR Calisthenics." These also included short body awareness exercises, led by the facilitator and spoken to the participant, such as breathing, feeling their feet on the floor, shrugging their shoulders, etc. These techniques were brought from slowdanger's own training and their classes in "Physical Integration."

Image: Dancer and Participant interact, with headset view on right

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