"How do I make this thing smile?": An Inventory of Expressive Nonverbal Communication in Commercial Social Virtual Reality Platforms

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ABSTRACT
Despite the proliferation of platforms for social Virtual Reality (VR) communicating emotional expression via an avatar remains a significant design challenge. In order to better understand the design space for expressive Nonverbal Communication (NVC) in social VR we undertook an inventory of the ten most prominent social VR platforms. Our inventory identifies the dominant design strategies for movement, facial control, and gesture in commercial VR applications, and identifies opportunities and challenges for future design and research into social expression in VR. Specifically, we highlight the paucity of interaction paradigms for facial expression and the near nonexistence of meaningful control over ambient aspects of nonverbal communication such as posture, pose, and social status.

Author Keywords
Virtual Reality; Social Interactions; Nonverbal Communication;

CSS Concepts
• **Human-centered computing~Virtual reality** • Human-centered computing~Collaborative and social computing systems and tools • Hardware~Emerging interfaces

INTRODUCTION
In the early 2000s, the rise of Virtual Worlds (VWs) led to increased scholarly attention to avatar mediated socialization in general, and Nonverbal Communication (NVC) in particular [60]. The current proliferation of similar social platforms in Virtual Reality (VR) affords scholars an opportunity to revisit these analytical and design frameworks through the lens of a new generation of online social environments. In this paper we present the results of an inventory of expressive Nonverbal Communication (NVC) on commercial social Virtual Reality (VR) platforms. Through an extended analysis of ten popular platforms for socialization in VR we have catalogued the design of the most common NVC behaviors at the user interface level. We collected data on the "out-of-the-box" functions for NVC control on each platform, including systems for proxemic spacing, facial expression control, gesture, posture, gaze fixation, and more. We situate this survey within a broader history of studies of NVC in and out of games and Virtual Worlds (VWs) in order to better consider how the design of expressive avatar behavior has evolved since the introduction of graphical shared virtual environments.

We ask the following research questions:

- **RQ 1:** For any given commercial social VR experience, what are the default Nonverbal Behaviors available to a first-time user?
- **RQ 2:** How are these behaviors enabled and controlled at the level of the user interface?

To address these questions, we undertook an inventory of the basic NVC functions of commercial social VR experiences. This work contributes to ongoing research into social interactions in virtual reality in several concrete ways. First, by focusing on commercially available systems, we are able to identify design strategies that are in use by real people in the world. Keeping our focus on commercial systems allow us to better anticipate how common design patterns might shape the expectations and literacies of current users of VR, which can inform how we approach the design of new solutions. This inventory of existing design strategies can help designers and researchers of VR applications avoid "reinventing the wheel" in their own work. Second, we identify gaps within the commercial design space for expressive VR which represent opportunities for future innovation in avatar-mediated online socialization. Finally, by comparing this data set with previous work on NVC in virtual worlds and online games, we can identify some "pain points" for researchers and designers of virtual social experiences, in particular by identifying problems that have remained unsolved or unsolvable throughout the history of these environments.

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This paper evaluates today's commercial social VR platforms through the lens of prior work on NVC in VWs in order to trace the trajectory of this design space and articulate an agenda for future design and scholarship in this domain. Our paper provides heuristics for better evaluating and comparing nonverbal communication design patterns across different social VR systems.

RELATED WORK

Basics of Nonverbal Communication

We draw much of this overview from Tanenbaum et al.'s book on *Nonverbal Communication for Virtual Worlds* [60]. While we summarize the most relevant histories and details here, including a full detail of its content is beyond the scope of a conference paper. We thus encourage interested readers to refer to this text for a more extensive discussion of NVC.

Foundations: Proxemics and Kinesics

Early work into NVC can be broken into two broad categories: proxemics and kinesics. Proxemics, the study of the relationships between human bodies in space, was coined by Edward T. Hall in *The Hidden Dimension* [26]. Hall's work describes zones of intimacy around the human body, including intimate, personal, social, and public, each of which depends upon contexts and demographics but have been suggested to be predicative of proxemic behavior. These proxemic behaviors are "semi-conscious" responses to others within proximity, whether that space is physical or virtual. This includes notions of comfort associated with mutual gaze, as described through equilibrium theory [2], in which proxemic spacing and mutual gaze may both be used to indicate intimacy.

Kinesics, on the other hand, concerns body language with respect to posture and gestures. Coined by Ray Birdwhistell in *Introduction to Kinesics*, Birdwhistell's unsuccessful attempt to identify a basic unit of movement through kinesics established the study of gesture and posture and ultimately led to more contemporary approaches for studying gesture and posture in NVC [6,32].

Contemporary Frameworks: Gesture and Cognition

Among these contemporary approaches, Paul Ekman's and Wallace Friesen's "Repertoire of Nonverbal Behavior" [20] addresses three fundamental issues in the field of NVC: a behavior's *usage*, its *origin,* and its *coding*. A behavior's *usage* refers to "regular and consistent circumstances surrounding the occurrence of a nonverbal act" [20] or, in other words, the context of a behavior. *Origin* deals with the three ways in which people learn behaviors, which include shared neurological responses, experiences of shared embodiment in the world, and the life experiences of any particular individual. Finally, *coding* refers to the relationship between behaviors and their communicated meanings, the varying degrees of abstraction between a nonverbal act and its signified meaning. Ekman and Friesen described coding through three principles, arbitrary, iconic, and intrinsic, which respectively describe meaning relationships that bear no resemblance to the meaning they signify, bear some resemblance to the meaning they signify, or bear direct relationship to the meaning they signify, respectively [20].

Ekman and Friesen then identified visual relationships between nonverbal acts and their meanings as well as high-level categories for nonverbal behavior, which were later nuanced by David McNeill by focusing on gestures "synchronized with the flow of speech" [41]. McNeill argued that gestural significance depended upon intention and, along with Cassell [16], defined their own categories for gestures which made the case for gestures and language to be seen in concert toward a fuller communication of thought that isn't well described by either without the other, positioning gesture and thought in a dialectic relationship, which connects to Lakoff and Johnson's work on image schema and embodied metaphor [37], and Bruner's work on the narrative mode of thinking [12,13]. More recently, McNeill and Duncan go as far as to suggest that language and gesture combine to form external, embodied cognition [42].

Social Signals for Expression and Performance

Vinciarellia et al. did similar work in classifying and categorizing social signaling behaviors in digital contexts through their social signaling framework, which analyzes social behavior in both human to human and human to computer interactions [68]. Their work incorporates elements of both proxemics and kinesics, describing social signals conveyed through behavioral cues which communicate a number of common functions, and is used in computer science and animation toward better means of communicating intention. Of particular interest to us are Vinciarellia et al.'s categories of social cues, which include "physical appearance", "gesture and posture", "face and eyes behavior", "vocal behavior", and "space and environment" [68].

We find some of the most rigorously applied frameworks for expressive movement within the performing arts. While a full survey of movement frameworks from dance and theatre is beyond the scope of this paper, we do want to highlight the utility of Laban's Movement Analysis (LMA) framework which informed several aspects of our understanding of expressive NVC. Laban divided movement into five categories: Body, Effort, Shape, Space, and Phrasing [4,19,34,38,40]. Tanenbaum et al. summarized LMA's movement categories, writing "the *Body* category is concerned with which body parts move and how movement starts and spreads throughout the body. *Space* describes the size occupied by gesture and the spatial pathways it follows. *Shape* describes changes in the body. *Effort* involves the qualities of movement and the energy used by it. *Phrasing* indicates the transitions that take place between movements." [60] (emphasis added) Theorists of expressive characters and animation use a variant of Laban's movement parameters created by Keith Johnstone, known as "fast-food Laban" [31], which draws three expressive dichotomies from LMA: sudden vs. sustained, light vs. heavy, and indirect vs. direct. Selecting a parameter from each dichotomy yields eight possible movement styles [Table 1].

Table 1 Movement Styles from Fast Food Laban [31]

Punching =	Sudden + Heavy + Direct
Pushing =	Sustained + Heavy + Direct
Slashing =	Sudden + Heavy + Indirect
Wringing =	Sustained + Heavy + Indirect
Dabbing =	Sudden + Light + Direct
Smoothing =	Sustained + Light + Direct
Flitting =	Sudden + Light + Indirect
Stroking =	Sustained + Light + Indirect

These movement styles have been employed by theorists and designers of expressive character movement to help concretize aspects of NVC in practice [57]. Johnstone also writes about the notion of "status" in theater performance, which he uses to consider power relationships between characters. Different postures and bodily movements can be employed to communicate dominance, or submission, where high-status individuals are upright and straight, while low-status are bent, or slack, or knotted [31]. For our purposes, Johnstone's work on status and fast-food Laban helped us to clarify our thinking around posture, mood, and other characteristics of movement that might be applied to a range of different expressive acts as a *modifier* or *style* of movement. For example, a character clapping in a sudden, heavy, and direct manner communicates something very different than a character clapping in a sustained, light, and direct manner.

More broadly, we draw on the above body of work to identify the primary nonverbal behaviors and social signals that we are interested in identifying within commercial social VR.

NVC in Virtual Worlds

Nonverbal communication in virtual worlds has been the subject of extensive research over the last 20 years as avatar-mediated socialization has moved out of the research lab and into relatively common usage [5,15,17,25,49,53,60,62]. As the consumer market and cultural significance of virtual worlds and online games has grown, more and more people have grown comfortable with the idea of engaging in meaningful social interaction with others via an avatar, game character, or other forms of virtual embodiment. With this comfort comes a host of attendant literacies, interaction conventions, and common practices that exist in a feedback loop between the (top-down) designed affordances of various online social platforms and the (bottom-up) practices of virtually embodied players seeking to communicate. Most commonly, players use text or voice to communicate in these environments, however a host of NVC elements also exist in virtual worlds and online games.

Early studies have established that certain categories of NVC translate into virtual environments. Of particular interest to our work is Bailenson et al's work on the impact of gaze in virtual worlds. Their work showed that not only were participants of virtual worlds likely to respect gaze proxemics, much as they might in the real world, but that as avatar realism increased, so too did participants' respect for those proxemics [2]. In a follow-up study, Bailenson et al further found, through refined experimentation, that "perception of agency," or the perception that virtual agents were actually real people, was a key factor, along with realistic gaze, in participants' respect for virtual proxemics [3]. Yee and Bailenson then went on to study the proxemics of gaze in second life, identifying measurements for interpersonal distance between avatars, concluding that "interactions in online virtual environments, such as *Second Life* are governed by the same social norms as social interactions in the physical world" [69].

Previous Work in Social VR

Over the last five years Virtual Reality (VR) technology has become better, cheaper, and more widespread than at any other point in history. As VR has started to proliferate, so to have networked social VR experiences. In many ways, these experiences resemble the virtual worlds that preceded them which is not surprising since some of today's most prominent commercial social VR experiences (including High Fidelity and Sansar) are being developed and operated by the same people who pioneered these virtual worlds in the mid-2000's. As with virtual worlds, in social VR, human interaction is mediated via avatars.

Recent studies of social VR have several common threads. Most of these studies found that current social VR platforms [43,46,48,50] and VR theater experiences [22,70] offer only limited affordances for expressive NVC. Bombari et al. identify nonverbal behavior as a significant design challenge for social interactions in Interactive Virtual Environments." [11] This was often stated in connection with the general consensus among many of the surveyed studies that VR platforms promoted increased engagement, either as direct engagement with activities [27,70], or participants [11,46,61], or affective engagement between participants [39,56], or between participants and virtual actors [22]. Thus, it comes as no surprise then that there is a good amount of recent scholarship devoted to improving NVC in VR systems through the creation of new systems [1,11,22,27,43,52,58,65,70]. Most of these studies focused on describing their design methods or evaluating design strategies. The work that is closest to our own here is that of Kolesnichenko et al, who have interviewed the designers of social VR systems in order to better understand how they approach the design of avatar systems [36]. While their approach is similar to ours, we apply Tanenbaum et al.'s work on NVC in Virtual Worlds [60] as an analytical lens and focus on the design affordances that are evident in the platforms themselves. As such, our work contributes to ongoing research into social interactions in virtual reality by similarly assessing the state of NVC in commercial social VR identifying the many gaps and opportunities for design strategies meant to improve engagement and build better systems.

METHODS

We set out to take inventory of the current affordances for socialization in virtual reality, with an emphasis on Nonverbal Communications and emotional expression. We restricted our review to existing commercial systems so that we could better understand how their designs might shape the emerging literacies of users within this space.

Our goal was to catalogue common design elements for avatar expression and identify gaps and opportunities for future design innovation. Given the rapid proliferation of both formal commercial platforms for social VR, and emergent social practices within VR, we made some careful choices about how to manage the scope of this work. We chose to focus our attention only on the default designed interface options for controlling avatars in virtual reality that are available to players within their first experience of a commercial social VR space. We made this decision in full awareness of the fact that that many of these environments offer user-customized options and advanced features that expert users may discover or purchase after lengthy immersion within these environments. The goal of this work is to establish a baseline understanding of the fundamental features for social interaction that are supported by commercial social VR platforms. Other forms of emergent NVC will form the basis for future work. We also recognize that many players often find ways to express complex nonverbal communications by deploying basic avatar functions in contextually and culturally distinct ways, allowing simple actions like jumping and crouching to stand-in for all manner of different communicative acts (see, for instance, “teabagging” in competitive online game play [47]). Such emergent situational communications are also outside the scope of this study. Instead, we report on the NVC behaviors that are formally and explicitly supported within the design of commercial social VR platforms. By focusing on the *default* affordances of these platforms we are able to identify a normative lexicon of NVC as understood within the commercial design space.

Methodologically, we undertook a systematic textual analysis of the design features of these platforms. Using Bizzocchi and Tanenbaum’s techniques for close reading digital media [7], we constructed an analytical lens, drawn from the body of literature around Nonverbal Communication in both physical and virtual environments. This lens provided a structure to our observations of commercial social VR platforms, allowing us to isolate and assess a large set of NVC behaviors. This method of textual analysis is quite common in media studies but is less well understood within HCI. Our approach is similar to that undertaken by Lindsay Grace in his analysis of affection

Table 2 Selected Commercial Social VR Platforms

Platform	Publisher	Headset Compatibility*
VR Chat	VRChat Inc.	OR, VIVE
AltSpace VR	Microsoft	OR, VIVE, MR, OTR
High Fidelity	High Fidelity Inc.	OR, VIVE
Sansar	Linden Lab	OR, VIVE
TheWave VR	WaveVR Inc.	OR, VIVE
vTime XR	vTime Ltd.	OR, MR, OTR
Rec Room	Against Gravity	OR, VIVE, PSVR
Facebook Spaces	Facebook	OR, VIVE
Anyland	Anyland	OR, VIVE, MR
EmbodyMe	EmbodyMe Inc.	OR, VIVE
**Key for Headsets: OR=Oculus Rift, VIVE=HTC VIVE, MR = Windows MR, PSVR= Playstation VR, OTR =Other (Samsung Gear VR, Daydream, Google Cardboard, Oculus Go)*		

games [23] and Giusti et al.’s work on weapon design patterns in shooter games [21], The unit and subject of analysis for this kind of work is the “design pattern” which exists in conversation with an anticipated player experience, but is also independently observable [8]. While we cannot claim to have inventoried every possible interface or design pattern for NVC in Virtual Reality, our dataset speaks to a representative cross section of the current design space that has direct utility for designers and theorists.

Selection Criteria and Platforms

To identify suitable commercial social VR platforms for this study, we first did a survey of ten “best-of” lists from around the web [9,24,33,35,44,51,54,55,59,63]. This generated a list of several dozen potential systems. We then narrowed down the list by applying the following criteria:

1. Is social interaction the central focus of the platform?
2. Is the platform primarily deployed for VR?
3. Can the platform be used with an Oculus Rift, HTC Vive, or Windows MR or comparable PC-based VR headset with motion controllers?
4. Is the platform relatively complete, and does it have an active population of users?

Many platforms from our initial list were primarily games or other kinds of playful VR experience, where social features were secondary to the core design. Others were non-VR platforms that had an optional (often alpha-test) VR mode. Many others on the list were defunct, or incomplete. Once accounting for all of these things, we were left with a list of ten commercial social VR experiences [Table 2].

Although we had access to a full complement of VR headsets, we elected to conduct all our data collection with the Oculus Rift, as it was the only one that was universally supported across all ten platforms.

Data Collection

Groups of 3-4 researchers collected the data, working together to identify and document NVC within our ten commercial social VR systems. This data was collected over the course of two months in January and February of 2019. One researcher was responsible for controlling the VR experience, while the other researchers observed their activities on an external monitor. Another researcher used our analytical lens to guide the VR researcher, asking them to attempt different activities as guided by the following eight questions:

1. Can the user control facial expressions, and if so, how? (Pre-baked emotes, puppeteering, etc.)
2. Can the user control body language, and if so, how? (Pre-baked emotes, puppeteering, postures. etc.)
3. Can the user control proxemic spacing (avatar position), and if so, how? (Teleport, hotspots, real world positioning, etc.) How is collision handled between avatars? (Do they overlap, push each other, etc.)
4. How is voice communication handled? Is audio spatialized, do lips move, is there a speaker indicator, etc.
5. How is eye fixation/gaze handled? (Do avatars lock and maintain gaze, is targeting gaze automatic, or intentional, or some sort of hybrid, do eyes blink, saccade, etc.)
6. Are different emotions/moods/affects supported, and how are they implemented? (Are different affective states possible, and do they combine with other nonverbal communications, etc.)
7. Can avatars interact physically, and if so, how? (Hugging, holding hands, dancing, etc.) What degree of negotiation/consent is needed for multi-avatar interactions? (One-party, two-party, none at all?)
8. Are there any other kinds of Nonverbal Communication possible in the system that have not be described in the answers to the above questions?

A third researcher was responsible for notetaking and transcription, writing down the information reported by the VR researcher in a spreadsheet with fields for each of the questions and sub-questions. For some platforms where multiple players were needed to produce and observe some of the NVC behaviors that we were interested in, a fourth researcher entered VR on a second system so that we could observe two users interacting with each other. The goal of this process was to document in as much detail as possible the design of these commercial social VR systems. We recorded details, not just about the software interface, but also about the specific button presses, body movements, and hardware interactions required for each interaction. The first time we encountered any given design strategy we wrote out detailed descriptions. When we subsequently encountered similar strategies on other platforms, we recorded notes about how they overlapped-with and/or diverged-from previous variants.

Data Analysis

Once data collection for each commercial social VR platform was complete, two members of the research team read through the collected data and undertook a categorization exercise to try and identify common design strategies across the systems. This initial analysis revealed some high-level categories of nonverbal behaviors that were supported by the platforms in our sample and allowed us to create an initial inventory of NVC for social VR. We then conducted a second, more structured analysis of the data where we identified specific design strategies within each category, as well as sub-strategies, or "features" that modified or augmented those design strategies. This analysis allowed us to produce a matrix of the NVC features afforded by each commercial social VR platform within our sample [Table 3]. In the following section we will unpack this matrix and explain each of our categories, design strategies, and their features.

Limitations

We recognize that our method has some limitations, first and foremost being the duration of our time collecting data from each platform. We spent about two hours within each experience collecting data. This was enough time to uncover most of the functions and features of these systems, but not enough to become virtuosic in our operations of them. We also recognize that by excluding games and other non-social VR experiences, we have limited our data in some particular ways. Of the nonverbal behaviors that we were interested in, movement and proxemics overlaps with the basic utilitarian function of "getting around" within a VR environment. Unlike many of the other social signals we looked at, like gaze and facial expression, movement is a nearly universal feature or VR, and our sample only contained a subset of the design strategies that have been developed for movement in VR. However, as discussed earlier, while our inventory is not 100% inclusive of all possible VR experiences, we contend that it is sufficiently representative of the space to have real utility for designers and researchers.

FINDINGS: AN INVENTORY OF NVC IN COMMERCIAL SOCIAL VR

In this section we discuss the specific contents of our inventory of Nonverbal Communication for Virtual Reality, as overviewed in [Table 3].

Overview of the Inventory

We divide our inventory into four high-level categories: (1) Movement and Proxemic Spacing; (2) Facial Control; (3) Gesture and Posture; and (4) Virtual Environment Specific NVC. The first three categories encompass three of the

Table 3 An Inventory of Default NVC Functionality for Commercial Social VR (as of January-February 2019)

Movement & Proxemic Spacing

	Direct Teleportation	*Facing Selection*	*Destination Validation*	*Vertical Movement*	Analog Stick Movement	*Smooth/Continuous*	*Snap/Step*	1:1 Player Movement	3rd Person Movement	"Hot Spot" Selection
Sansar	✓		✓	✓	✓			✓		
AnyLand	✓			✓				✓		
TheWaveVR	✓	✓	✓	✓				✓		
vTime XR										
Embody Me	✓	✓	✓	✓				✓		
High Fidelity	✓	✓	✓	✓	✓		✓	✓		
AltSpace	✓		✓	✓	✓	✓	✓	✓		
Rec Room	✓		✓	✓	✓	✓	✓	✓		
Facebook										✓
VR Chat					✓		✓	✓	✓	

Facial Control

	Expression "Preset	*Independent/Direct Selection*	*Dependent/Indirect Selection*	"Puppeteered" Expressions	*Lip Sync*	Gaze & Eye Fixation	*Object Tracking*
Sansar				✓	✓	✓	
AnyLand	✓	✓					
TheWaveVR					✓	✓	✓
vTime XR	✓	✓	✓		✓	✓	✓
Embody Me	✓	✓			✓		
High Fidelity					✓		
AltSpace					✓		
Rec Room	✓	✓			✓		
Facebook	✓	✓			✓	✓	✓
VR Chat	✓	✓	✓			✓	

Gesture & Posture

	Poseable Appendages	*Hands/Arms*	*Head*	*Torso*	*Legs*	Dependent/Indirect Selection	Mood, Posture, and Status	*Dependent/Indirect Selection*	*Mood Preset*
Sansar	✓	✓	✓	✓		✓			
AnyLand	✓	✓							
TheWaveVR	✓	✓	✓						
vTime XR	✓	✓	✓	✓					
Embody Me	✓	✓	✓	✓					
High Fidelity	✓	✓	✓			✓			
AltSpace	✓	✓	✓				✓		✓
Rec Room	✓	✓	✓	✓			✓	✓	
Facebook	✓	✓	✓	✓					
VR Chat	✓	✓	✓	✓	✓	✓	✓	✓	

Virtual Environment Specific NVC

	Multi-Avatar Interactions	*Consent*	Collisions	*With other Avatars*	*With Environment*	Emotes	POV Shift
Sansar			✓		✓	✓	✓
AnyLand			✓		✓		
TheWaveVR			✓		✓		
vTime XR	✓						
Embody Me			✓		✓		
High Fidelity	✓	✓	✓		✓	✓	✓
AltSpace	✓	✓	✓		✓		
Rec Room	✓	✓	✓		✓		
Facebook	✓						
VR Chat	✓	✓	✓	✓	✓	✓	✓

primary modes of NVC that have been identified within the physical world, while the fourth addresses aspects of nonverbal communication that must be uniquely attended to within a virtual environment due to both the limits of the technology used for these platforms, and due to the lack of certain constraints that are endemic to the physical world.

Category 1: Movement/Proxemic Spacing

In 2017 Costas Boletsis published an exhaustive review of contemporary research into VR locomotion [10]. He produced a typology of four primary techniques for movement, including *motion-based* movement, *room scale-based* movement, *controller-based* movement, and *teleportation-based* movement. Boletsis's typology draws on a much larger data set than our study, but it confines itself to a survey of the literature, rather than being situated within a set of accessible VR experiences. Thus, while there is much overlap between these types, we have undertaken our own categorization of movement in VR, which emerges from experiences that are more typically accessible to an everyday user of social VR. This category contains the following five design strategies, some of which, in turn contain specific sub-features.

Direct Teleportation was the most common strategy evident in our data set occurring within seven of the ten systems we evaluated. Direct Teleportation is a form of what Boletsis calls *teleportation-based* movement [10]. With direct teleportation the user pushes a button on the controller, which causes a target to appear on the ground where they are pointing, connected back to the user with visible line or arc. By moving the controller, they may position the target at a desired destination. Releasing the button then teleports the user to the new location. There are several design features that can augment direct teleportation, including:

- *Facing Selection:* Allows the player to designate a direction that they want to be facing when they arrive at their destination, often using the analog sticks on the controllers to move through a 360-degree rotation.
- *Destination Validation:* Designates whether the player is permitted to teleport to a specific destination, often through color-coding.
- *Vertical Movement:* Permits the player to teleport across multiple levels or vertical planes.

Analog Stick Movement was present in five of the systems we inventoried. Analog stick movement is a form of what Boletsis calls *controller-based* movement [10]. It is similar to movement in console videogames, where an analog joystick is used to move the character within the virtual environment. Of the strategies we identified, this one was the most likely to produce nausea or vertigo among our researchers[1]. We identified two common variants of this strategy:

[1] Nausea, disorientation, and vertigo are significant recurring problems for designers of VR systems. We encountered two strategies within our social VR platforms for reducing these negative effects: *vignetteing*, which reduces peripheral vision and narrows field of view while in motion, and saccades, a feature that offers a brief blinking to black during transitions.

- *Smooth and Continuous Movement:* Moves the player through space with no view obstructions like head bobbing or jarring motion. This feels like flying or gliding.
- *Snap-Step Movement:* Snaps the player forward, backwards, or sideways the distance of a "step". This allows players to fine-tune their position in space, and essentially operates like a micro teleport.

1:1 Player Movement is a form of what Boletsis calls *room scale-based* movement [10], wherein the relative position of the player's body in their physical play space is mapped directly to the position of the avatar in VR. This was present in most of our systems, with the exception vTime and Facebook Spaces, where the virtual avatar is seated. Interestingly, while most systems had 1:1 movement, only two of the platforms in our study incorporate inverse kinematics to animate the avatar's legs in response to changes in the headset position: VR Chat, and High Fidelity.

Third Person Movement is a rare variant of teleportation-based movement that only occurred in VR Chat. The player uses a teleportation arc to place a moveable target in the environment. The player's avatar immediately starts to walk towards that arc in real-time while the player's point of view stays in the initial starting position. Releasing the teleport button causes the player's POV to jump back into that of the avatar. The avatar stops when the movement button is released, so it need not always arrive at the destination projected via the interface arc, and it is possible to lead the avatar around with the arc, since the avatar moves at a fixed speed.

"Hot Spot" Selection is the final locomotion strategy that we observed, and it only occurred once in our dataset, in Facebook Spaces. This strategy doesn't have an immediate corollary in Boletsis's taxonomy. In Facebook Spaces, all interactions take place around a shared table, with "seats" for the users. It is possible to jump from seat to seat, but no other movement is supported.

Category 2: Facial Control

In 2018, Moustafa and Steed produced a longitudinal study of group interaction in social virtual reality which called for a need of more accurate facial expression in VR [46]. They found that the lack of dynamic facial expressions negatively impacted socialization between strangers in VR noting that particular groups found it uncomfortable that facial expressions were not accurately represented in VR spaces. One group specifically mentioned that the lack of facial expressions within the social VR experience resulted in "uncomfortable sessions." Our surveyed commercial social VR platforms handle facial expression and representation to varying degrees. This form of NVC allows players to communicate using their avatar's facial features. This category contains the following three design strategies of which in turn have specific sub-features.

Expression Preset was present in seven of the ten systems we examined. This refers to giving the user selectable or templatized facial expressions as complete items available to choose from in menus or interfaces, as opposed to pupeteered in an analog space, or on a per-facial-feature basis. We identified two approaches to preset facial expressions:

- *Independent or Direct Selection:* allows the player to choose from a list of preset expressions or avatars in a menu or interface.
- *Dependent or Indirect Selection:* refers to facial expressions which are connected to other emotes or behaviors that cannot be directly controlled by the player.

An example of *dependent or indirect selection* is VR Chat, where avatar faces are immobile except when an "emote" is playing, in which case sometimes there is an accompanying expressive facial expression. The best example of *independent or direct selection* can be found in Facebook Spaces, where different combinations of directional presses on the controller's analog sticks would yield different facial expressions until the sticks were released back to a neutral position.

Puppeteered Expressions were present in eight of the ten platforms we studied, but only in a very limited sense. For our purpose, we distinguish puppeteered expressions from preset expressions by the *granularity* of control afforded to the player. Where preset expressions might look like pre-defined facial rigs for laughing, or crying, or surprise, or anger, puppeteered facial rigs allow users the ability to control and compose individual facial features (or linked constellations of features) through a range of possible expressions to varying degrees. Thus, a user might puppeteer an expression from slightly smiling to grinning broadly, or to any point in-between those extremes. Within the systems we studied, only one had any sort of dynamically controllable facial expressions: Sansar changed the facial expression based on volume of the audio input from the user. The only aspect of the face that was dynamically controllable across multiple systems was the mouth of the avatar, which was puppeteered by audio input, as described in the one sub-category we were able to identify:

- *Lip Sync:* When the movement of the avatar's lips or mouth synchronizes with the player's voice audio. From our observations, Facebook Spaces had the most accurate lip movement as it was determined shape of the mouth by player's pitch and tone.

Gaze/Eye Fixation is the last facial control strategy present in the systems we surveyed. As discussed above, mutual gaze is an important social signal that we use to regulate intimacy [2,66]. While some eye fixation was observable in five of the ten platforms we observed, this function was largely outside of the user's control. In VR Chat, for example, gaze direction shifted seemingly at random. Sansar allowed us to "lock" our gaze onto an object or player by pressing the triggers on the controller. The three remaining systems used the following strategy:

- *Object Tracking:* Allows the avatar's gaze to follow the closest object in line of sight.

Category 3: Gesture and Posture

Pittarello and Franchin created a VR theater experience called PlayVR in 2016 which focused on the "different levels of cognitive and emotional involvement" of the player when in virtual reality [52]. They highlight the importance of gesture-based input when accurately communicating how an actor feels in VR. While creating PlayVR, they "consider[ed] both immersive VR and gesture-based interaction important components in design." This emphasis on gesture and posture as essential components of design that Pittarello and Franchin mention is also present in the VR systems we documented. Gesture and Posture are forms of NVC that communicate how a player feels via movement of select avatar appendages. We encountered several instances where the player could move certain parts of their avatar to convey feeling. This category contains the following three design strategies of which in turn have specific sub-features that assist in mapping player gesture and posture in virtual spaces:

Poseable/movable Appendages was the most common form of gesturing in VR and was present in all ten examined systems. It refers to the avatar's body movement changing in response to the player's movement of head, torso, arms and legs in their play space. This is one of those avatar puppeteering features that was not readily available in virtual worlds [67] that has meaningfully improved thanks to the standardization of motion controllers for the major VR headsets. This category allows players the potentially move the following appendages:

- Hands and Arms
- Head
- Torso
- Legs and Feet

Table 3 details which system allows for movement of which appendages. While hands and head can be mapped directly to input from the headset and controllers, arms, torso, legs, and feet all act as "children" to those other signals, following and responding to their actions.

Dependent/Indirect Selection is present in three of the ten systems we inventoried. Dependent/Indirect Selection is when body language is connected to other emotes that cannot be directly controlled by the player.

Mood/Status/etc. is present in three of the ten systems we surveyed, Mood/Status/etc. is behavior that reflects the avatar's overall emotional state. We identified two design features unique to this category:

- *Dependent or Indirect Selection*: When mood or status is connected to other emotes or behavior that cannot be controlled by the player. For example, in VRChat, emotes may have associated moods that accompany them. Emoting presents an accompanied mood which overrides all other modes of expressions.
- *Mood Preset:* Allows the player to choose from a menu or interface of templatized/selectable moods, statuses or emojis as complete items.

Category 4: Virtual Environment Specific NVC

As we surveyed our VR systems, we encountered features that were significant but unique in that they did not conform to an already existing category of NVC. Therefore, this NVC class features standalone cases that warrant their own section. We've identified four special elements used by our documented systems to manage a variety of interactions.

Multi-Avatar Interactions are present in six of the ten observed platforms and are defined as interactions—not necessarily physical—made with other player avatars. For example, in RecRoom, players can high five each other. Unlike the physical world, where physical contact between people requires socially negotiations, physical contact in VR is a property of the physics of the world that must be materially enabled or disabled. For this reason, we collected data on how our different platforms handled issues of consent between avatar bodies:

- *Consent*: In VR, consent is usually handled via a togglable privacy setting that must be disabled before another avatar can enter one's personal space. For example, in VRChat, new players by default begin with the "personal space" feature enabled. This prevents other avatars from entering the player's immediate virtual space.

Collisions were documented in eight of the ten platforms we tested and refer to physical encounters with objects or other player avatars. We found two features specific to this category:

- *Collisions with other avatars*: for example, in VRChat, there exists a togglable feature that allows other avatars to phase through the player avatar.
- *Collisions with objects and walls*: for example, in Embody Me, players are confined to a space bound by walls that are impassable.

Emotes are a standalone category that often encompasses other kinds of NVC but are packaged into preset animations that are often selected from a menu or interface. This is the most common form of expressive NVC in both virtual worlds and virtual reality.

POV Shift is a feature that allows the player to change the position of the camera in virtual space. This in turn allows the player to see more or less of their avatar. For example, in High Fidelity, the player has an option to toggle the camera from first to third person point of view.

DISCUSSION: CHALLENGES AND OPPORTUNITIES FOR THE DESIGN OF EXPRESSIVE NVC IN VR

Having inventoried the current state of NVC in VR, we turn our attention to the broader questions that we opened this paper with.

Applying the NVC Inventory to Design

VR development is proliferating rapidly, but very few interaction design strategies have become standardized. Further, very few people have spent any significant time in VR, outside of a small population of early adopters. This impacts the development of conventions and literacies. By better understanding the existing commercial design space, we can make informed choices about which features to include in our experiences. This also helps us better anticipate the expectations of our users, the extent to which they will bring pre-existing literacies, or confounding experiences to the interaction. For instance, we can say with some confidence that the conventions around direct teleportation are more mature and recognizable than any of the other movement strategies that we observed in our data. We can also say that most of the locomotion strategies we observed in action are not mutually exclusive. Some systems productively integrated multiple locomotion strategies, each intended to address a different context.

We view this inventory as a first step towards establishing a more comprehensive guide to the commercial design space of NVC in VR. As a design tool this has two immediate implications for designers. First, it provides a menu of common (and less common) design strategies, and their variations, from which designers may choose when determining how to approach supporting any given kind of NVC within their platform. Second, it calls attention to a set of important social signals and NVC elements that designers must take into consideration when designing for Social VR. By grounding this data in the most commonly used commercial systems, our framework can help designers anticipate the likelihood that a potential user will be acquainted with a given interaction schema, so that they may provide appropriate guidance and support.

Gaps in the Commercial Design Space

Our dataset also highlights some surprising gaps within the current feature space for expressive NVC. While much social signaling relies upon control of facial expression, we found that the designed affordances for this aspect of NVC to be mired in interaction paradigms inherited from virtual worlds. Facial expression control is often hidden within multiple layers of menus (as in the case of *vTime*), cannot be isolated from more complex emotes (as in the case of VR Chat), hidden behind opaque controller movement (as in *Facebook Spaces*), or unsupported entirely. In particular, we found that with the exception of dynamic lip-sync, there were no systems with a design that would allow a user to directly control the face of their avatar through a range of emotions while simultaneously engaging in other forms of socialization.

There is a bigger gap within the commercial design space that this points us toward. As we saw in our consideration of the foundations of NVC in general, and Laban Movement Analysis in particular, much NVC operates by layering together multiple social signals that modify, contextualize, and reinforce other social signals. Consider, for instance, that it is possible to smile regretfully, laugh maliciously, and weep with joy. People are capable of using their posture to indicate excitement, hesitation, protectiveness, and many other emotional states, all while performing more overt discourse acts that inherit meaning from the gestalt of the communicative context. We observed no such capacity for recombining and blending NVC within any of the commercial social VR platforms we considered.

Looking at our third category, gesture and posture, we see that intentional gestures are broadly supported within these platforms, but that *passive* or *unconscious* forms of posture remain outside of the designed affordances of these systems. Such uses of NVC often serve as background signals for more intentional communication: not only can posture convey mood and affect, it can convey idiosyncratic aspects of personality, social status, dominance and submission, and culturally specific mannerisms. Our data highlights how little of this is present within the current commercial landscape of social VR.

Longstanding Challenges for Expressive Avatar Behavior

With a few exceptions (such as hand and arm gestures, & puppeteered head movement), VR reproduces many of the same problems that Virtual Worlds have grappled with for NVC. As discussed above, many forms of NVC happen unconsciously, or pre-consciously. Theatrical disciplines and craft around NVC try to foreground these kinds of behavior through techniques like fast-food Laban and "status" [31] which provides a template for how these unconscious actions might be incorporated into more conscious expression. One of the biggest challenges in this space is determining how much these behaviors should be under the explicit control of the player, vs. being controlled automatically by the software engine. In some systems, things like eye blinking and other micro-gestures are already automated. Moving forward, a critical question that our study raises is: to what extent is control over an avatar entirely the domain of the user, vs. the designer? Relatedly. how much attention should a user need to devote to NVC and how often should they do so? Can we create systems that responsively automate unconscious social signals so that users need not distract themselves from the conscious communication that they are engaged in.

Finally, in the physical world we can feel what our bodies are doing. This sense of our own embodiment is known as *proprioception,* or *kinesthetic sense.* This awareness of our own embodiment impacts how we perceive and experience the world, and our interactions with each other in it. McNeill's work [41] highlights how our experiences of physical motion help us form thoughts and intentions. VR already moves us much closer to this kind of embodied cognition for gross motor movement, but it doesn't capture the impact of smiling or other more subtle motions. A central challenge for designers of social VR systems is: how do we mirror body language back to users to support their own process of embodied cognition?

CONCLUSIONS

In this paper we have reported on our inventory of expressive nonverbal communication in current commercial social virtual reality experiences. As is evident in the scholarly work around social VR, improving the design space for NVC in VR has the potential to facilitate deeper social connection between people in virtual reality. We also argue that certain kinds of participatory entertainment such as virtual performance will benefit greatly from a more robust interaction design space for emotional expression through digital avatars. We've identified both common and obscure design strategies for NVC in VR, including design conventions for movement and proxemic spacing, facial control, gesture and posture, and several strategies unique to avatar mediated socialization online. Drawing on previous literature around NVC in virtual worlds, we have identified some significant challenges and opportunities for designers and scholars concerned with the future of socialization in virtual environments. Specifically, we identify facial expression control, and unconscious body posture as two critical social signals that are currently poorly supported within today's commercial social VR platforms.

Thus far we have only discussed interaction designs that fit within the capabilities of the current generation of VR headsets and controllers. We recognize that the development and proliferation of new hardware devices could well render some of our claims here obsolete. For instance, many developers and researchers have been investing in real-time facial mapping, which might allow users to control avatar facial expressions with their own faces. While the technology for puppeteering animated characters with a camera has existed for a while, this has been difficult to adapt to VR, due to the presence of the VR headset, which obscures the face of the user. However, solutions to this problem are starting to emerge from research labs, as exemplified by Thies et al.'s FaceVR system [64]. However, such approaches are costly to implement, and are many years out from becoming accessible to the average user. In this sense, they resemble the many different attempts at omnidirectional treadmills and other similar locomotion devices that were seen as necessary for locomotion in VR (such as the Cyberith Virtualizer [14], the Virtual Perambulator [29], the CirculaFloor [30], the Omni-Directional Treadmill [18], and the Torus Treadmill [28]) but which have remained inaccessible to the everyday user of VR. For this reason, we have focused on the design strategies possible within the current commercial space for social VR.

Future Work

As adoption of social VR increases, we see a need for new design patterns and conventions that can be integrated into existing platforms. Having identified some challenges and opportunities, we have already begun to develop and evaluate research prototypes for new forms of expressive avatar puppeteering.

We can imagine a system where the user doesn't simply customize the appearance of their avatar (an action which, in itself is a significant form of NVC [45]). In this system, the user might get to choose characteristics of gait and locomotion, they might choose whether their avatar slumps or stands up straight. They may define a series of "tics" and idle behaviors that are particular to their avatar. We can imagine that once the user crafts a range of automated mannerisms, that these might then operate automatically in the background, or be contextually triggered by other more intentional behaviors.

We can imagine a lightweight facial puppeteering interface, where users can craft a set of facial behaviors and animate them using movements of their head and hands.

Much work remains to be done in order to realize the potential of VR as a platform for socialization and expression. The inventory presented in this paper takes an important first step to understanding the commercial design space for expressive avatar behavior in VR. The design patterns we identify and discuss may be viewed as heuristics for comparing and evaluating the affordances for NVC in social VR systems. Our inventory represents a snapshot of avatar mediated socialization in VR in 2019 and may be used as a benchmark for future investigations of online nonverbal communication.

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