The Social and Behavioral Influences of Interactions with Virtual Dogs as Embodied Agents in Augmented and Virtual Reality

Nahal Norouzi
University of Central Florida

THE SOCIAL AND BEHAVIORAL INFLUENCES OF INTERACTIONS WITH VIRTUAL DOGS AS EMBODIED AGENTS IN AUGMENTED AND VIRTUAL REALITY

by

NAHAL NOROUZI
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ABSTRACT

Intelligent virtual agents (IVAs) have been researched for years and recently many of these IVAs have become commercialized and widely used by many individuals as intelligent personal assistants. The majority of these IVAs are anthropomorphic, and many are developed to resemble real humans entirely. However, real humans do not interact only with other humans in the real world, and many benefit from interactions with non-human entities. A prime example is human interactions with animals, such as dogs.

Humans and dogs share a historical bond that goes back thousands of years. In the past 30 years, there has been a great deal of research to understand the effects of human-dog interaction, with research findings pointing towards the physical, mental, and social benefits to humans when interacting with dogs. However, limitations such as allergies, stress on dogs, and hygiene issues restrict some needy individuals from receiving such benefits. More recently, advances in augmented and virtual reality technology provide opportunities for realizing virtual dogs and animals, allowing for their three-dimensional presence in the users' real physical environment or while users are immersed in virtual worlds.

In this dissertation, I utilize the findings from human-dog interaction research and conduct a systematic literature review on embodied IVAs to define a research scope to understand virtual dogs' social and behavioral influences in augmented and virtual reality. I present the findings of this systematic literature review that informed the creation of the research scope and four human-subjects studies. Through these user studies, I found that virtual dogs bring about a sense of comfort and companionship for users in different contexts. In addition, their responsiveness plays an important role in enhancing users' quality of experience, and they can be effectively utilized as attention guidance mechanisms and social priming stimuli.

To my family.

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CHAPTER 1: INTRODUCTION

Intelligent virtual agents (IVAs) have been researched for many years, with several scientific conferences and workshops specifically devoted to the exploration and presentation of IVAs' evolution and their benefit to humans' lives, such as over 20 years of proceedings of the International Conference on Intelligent Virtual Agents[1] and International Conference on Autonomous Agents and Multiagent Systems[2]. More recently, beyond research laboratories, many of these IVAs have become commercialized and widely used by many individuals in the form of intelligent personal assistants, such as Amazon Alexa, Apple Siri, and Google Assistant. While the majority of these commercialized IVAs are disembodied–only allowing for speech-based interactions, there is a long history of research on embodied IVAs that can be the foundation for their future availability either through ubiquitous technology such as cell-phones or the growing market of virtual reality and augmented reality devices.

The majority of IVAs, regardless of their embodiment and their developmental life-cycle, are anthropomorphic, and many are primarily developed to resemble real humans entirely [189]. Additionally, most of these IVAs are task-oriented, with some geared towards facilitating a wide range of general tasks, such as intelligent assistants [189] and others facilitating specialized interactions, such as the use of embodied IVAs for education and training [66, 190, 241, 274], with less attention on IVAs providing companionship and comfort to real human users (see [189] for application areas of embodied IVAs in augmented reality.)

However, real humans have more diverse interactions in the real world, and many receive various benefits, such as social support from interactions with non-human entities [9, 119, 206]. For in-

[1]https://dl.acm.org/conference/iva

[2]https://dl.acm.org/conference/aamas

stance, the APPA National Pet Owners Survey found that 70% of US households are pet owners, with dogs being the most common pet represented by 69 million households [12]. Similar trends are seen globally. For instance, in a 2016 survey of consumers worldwide, 57% identified themselves as pet owners, with dogs as the most common pet at 33% [202]. Specifically, research shows that the interactions between real humans and real dogs can bring about a variety of mental, social, and physical health benefits to humans studied by human-animal interaction researchers [30, 267] (see Figure 1.1).

However, certain limitations, such as allergies, hygiene issues [100], stress on dogs [200], training cost [96, 264], inability to provide adequate care, and public space laws [167] restrict specific individuals from receiving such benefits. For instance, many hospitals have therapeutic programs

(a) Photo by Fabian Gieske on Unsplash (b) Photo by Josh Hild on Unsplash

Figure 1.1: Photos of human-dog interaction.

where patients can interact with therapy dogs; however, such interactions are usually episodic and are not available to all the patients who can benefit from them, such as immunocompromised patients.

Over the years, aligned with advances in technology, alternative solutions, such as robotic and virtual dogs and animals, were studied for various use cases and populations [6, 7, 57, 76, 117, 165, 172, 215, 249, 258, 263]. More recently, augmented reality (AR) and virtual reality (VR) technology advances provide opportunities for realizing virtual dogs and animals, allowing for their spatial presence in the users' physical environment or while users are immersed in virtual worlds. For instance, compared to previously studied 2D virtual animals, the spatial presence of virtual animals can provide a more realistic experience, an effect which was observed during a similar comparison with virtual humans [78, 79].

In this dissertation, I motivate my choice to focus on virtual dogs in light of the various benefits of interactions with real dogs and identify and present a research scope to navigate the space of human-virtual dog interaction. Afterward, I present four experiments to understand the design of virtual dogs in AR and investigate opportunities for utilizing them as embodied IVAs existing in AR/VR spaces to fulfill various roles, such as companionship and guidance.

1.1 Motivation

The long history between real humans and real dogs and their extensive and influential roles in the lives of many individuals is the primary motivation for a deeper exploration of virtual dogs, in advance of other animals and non-humanoid entities, especially, in light of the novelty of previous research on non-humanoid IVAs.

Over the years, various research contributions focused on pinpointing the beginning and progression of the domestication of dogs through genetic analysis [111]. For instance, remains of wolves– the closest ancestors to dogs, and humans were found buried together dating back 100,000 years [111]. The earliest DNA evidence of dogs goes back to 30,000 years [111] with “true domestication” of dogs being dated back to 14,000 years ago [31]. Historically, dogs have assumed a wide range of roles starting with hunting, guarding, and companionship–roles that continue today [31, 264]. Additionally, due to specific training and breeding processes, the range of services through which dogs benefited human society expanded. For example, dogs are commonly used in service roles, such as the assistance of individuals with disabilities and detection of certain diseases [264, 267].

In the past 30 years or so, the realm of human-dog interaction (HDI) research has received considerable attention both directly reflected in the work of HDI researchers and indirectly through the number of publications over the years captured through literature reviews [30, 31, 111, 175]. HDI research contributions can broadly be grouped into two general categories of *Human Effects* and *Socio-Cognitive Aspects* shown in Figure 1.2. I refer to the different areas of research illustrated in blue on the left side of Figure 1.2 as the Human Effects category. The Human Effects category mainly focuses on the human side of the HDI and revolves around the identification and assessment of the effects of interactions with dogs on humans and how humans perceive dogs’ behaviors and expressions [30, 40, 137, 245, 266]. I refer to the different areas of research illustrated in green on the right side of Figure 1.2 as the Socio-Cognitive Aspects category. The Socio-Cognitive Aspects category mainly focuses on the dog side of HDI and revolves around the evolution of dogs and understanding their cognitive abilities and social behaviors on their own and/or compared to other species, such as wolves and chimpanzees [111, 175].

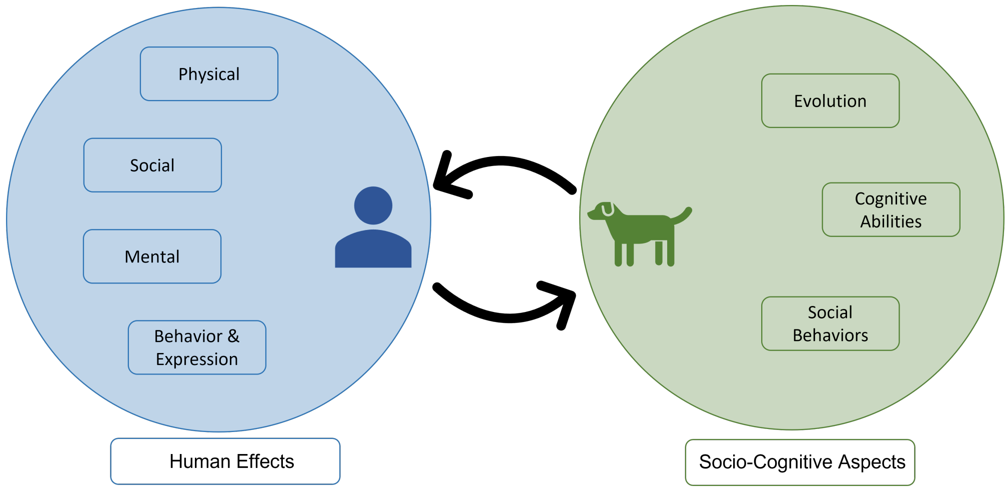


Figure 1.2: Categorization of HDI research with the left side focusing on the effects on and perceptions of humans and the right side focusing on understanding dogs as a species.

1.1.1 Human Effects Category

In the Human Effects category, several literature reviews aimed at identifying and categorising the effects of interactions with animals on humans [30, 91, 184, 267]. It is important to note that although researchers in many of these contributions include the broader scope of all investigated animals (e.g., dog, cat, horse, and aquatics), the majority of published contributions are based on findings from interactions with dogs. In this dissertation, I am primarily utilizing the previous work by Wells [267] and Beetz et al. [30] to expand upon the Human Effects category as they adopted a broader scope for their inclusion criteria in terms of the role of the animals and the nature of their relationship with the humans. Wells conducted a review of the effects of animals on human health and broadly presented these effects based on humans' physical or psychological health and well-being [267]. In her work, physical health included aspects, such as humans' assessment of their physical well-being and the improvements to their physiological signals due to interactions or the mere presence of animals, and psychological health included factors such as social health, depression, and self-esteem. Beetz et al. introduced four major areas where positive effects of interactions with animals were observed in humans [30]. In summary, these four areas point towards enhancements of (1) social attention, (2) physiological parameters of stress, (3) perceived fear and anxiety, and (4) mental and physical health. In this dissertation, I adopt and merge the areas identified by Wells [267] and Beetz et al. [30], and present three major categories of (1) physical, (2) mental, and (3) social effects of interactions with animals and most commonly dogs. In summary, their analysis suggests that animals and mainly dogs play an important role in humans' social life by acting as a social catalyst and have positive mental and physical effects, such as reducing humans' stress and anxiety both physiologically and by influencing their perception. Additionally, another research area in the Human Effects category focuses on how humans perceive dogs' expressions and behaviors and how dogs' communication signals can be utilized to guide humans in a general sense or in the context of a specific role [40, 137, 245, 261]. This concludes the four areas I am including under the Human Effects category, illustrated on the left side of Figure 1.2.

1.1.2 Socio-Cognitive Aspects Category

In the Socio-Cognitive Aspects category captured in the right side of Figure 1.2, Kaminski et al. [111] provided an overview of the literature exploring different hypotheses on the effects of domestication on dogs' cognitive abilities and social behaviors in response to humans. Interestingly, there is no clear consensus on the perceived superiority of dogs in understanding humans' communication cues compared to other species, with findings presented both in support or against the hypothesis that dogs, compared to other species, are naturally adept in understating humans due to their long shared history [111]. However, both research findings in support or against this hypothesis agree on the fact that dogs have a unique sensitivity and attachment towards humans [111, 272]. This heightened sensitivity and attachment, among other factors, may explain dogs' utilization compared to other animals in various service roles where the ability to be trained or conditioned has been deemed an important factor [264].

1.1.3 Utilizing HDI and Transitioning to Virtual Dogs

As stated earlier, interactions with real dogs can bring about various social, mental, physical health benefits for real humans. While I could have chosen any type of animal for the purpose of understanding virtual animals, the extensiveness of the benefits of interactions with real dogs inspired me to primarily focus on virtual dogs within the bounds of this dissertation.

Also, considering that the Socio-Cognitive Aspects of virtual dogs can go beyond what real dogs are capable of doing, within the scope of this dissertation, I have not studied the Socio-Cognitive Aspects category and only utilized findings from the Human Effects category. That said, within the scope of this dissertation, I investigate virtual dogs that have similar appearances and behaviors to their real counterparts within the bounds of available technology.

Overall, due to the novelty of research on embodied IVAs visualized as virtual animals or virtual dogs (see Section 2.2.2), the path for utilizing the HDI knowledge to transition to interactions with virtual dogs is less straightforward. This added novelty opens up new research questions concerning the research considerations for virtual dogs as embodied IVAs (e.g., behavior, appearance) and the roles they can fulfill.

1.2 Research Approach

To identify how the research considerations noted above were studied and addressed in previous research, I conducted a systematic literature review on embodied AR agents in head-mounted display (HMD) based environments [189]. This review led to the identification of five main research categories of embodied AR agents in HMD-based environments in the past 20 years, which are: (1) Visual Representation, (2) Displays and Interfaces, (3) Physical-Virtual Interactivity, (4) Proxemics, and (5) Behavior and Traits (see Figure1.3).

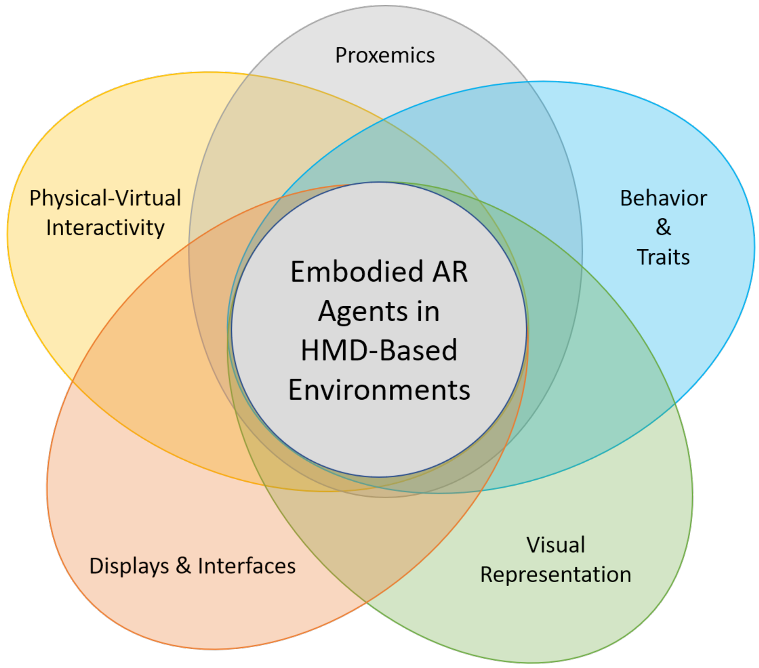


Figure 1.3: Primary research areas of embodied AR agents in HMD-based Environments [189].

The Visual Representation category is concerned with aspects, such as the presence of embodiment compared to voice-only interactions, agent type (e.g., human, animal, or robot), and agent size. The Displays and Interfaces category focuses on the influences of different display mediums (e.g., AR, VR, desktop), user interfaces (e.g., speech-based, gesture-based), and properties of these two elements (e.g., the field of view of the display) on the quality of interaction with embodied agents. The Physical-Virtual Interactivity category is concerned with the embodied AR agents' awareness of and responsiveness to the physical world and its ability to influence the physical environment. The Proxemics category studies how users maintain their spatial relationship with embodied AR agents and how agents' proxemics behavior influences them. Last, the Behavior and Traits category is concerned with the influences of embodied AR agents' behaviors and personality traits on the user's perceptions and behaviors. Although the research considerations when utilizing VR technology are not separately explored in this dissertation, similar research categories exist in all identified areas except the physical-virtual interactivity, which is specific to AR interactions. In the remainder of this dissertation, I will refer to these five identified areas as *Research Considerations*.

I used these five Research Considerations and the Human Effects category identified earlier to define a research scope that can be used to navigate the space of interactions with virtual dogs in AR/VR, hence entitled as the *Human-Virtual Dog Interaction* research scope. Table 1.1 shows this research scope and the four experiments I conducted to understand the design requirements of virtual dogs and their potential roles. However, it is important to note that this research scope and the four experiments are just the beginning steps of understanding virtual dogs and virtual animals, and more future research outside of the scope of this dissertation is required to gain a more comprehensive view of these entities as embodied IVAs similar to the historical research on humanoid embodied IVAs in the past 20 years.

		Research Considerations				
		Physical-Virtual Interactivity	Proxemics	Visual Representation	Behavior & Traits	Display & Interfaces
	[Exp 1] Design	√	√		√	
Human Effects	**[Exp 2]** Physical Effects **[Exp 2]** Mental Effects			√		
	[Exp 4] Social Effects		√	√		
	[Exp 3] Behavior & Expression			√	√	

Table 1.1: Human-Virtual Dog Interaction research scope: convergence of the Human Effects category and Research Considerations for embodied IVAs. Check marks present the Research Considerations explored within each chapter.

1.3 Thesis Statement

The overarching structure of the thesis statements and the chapters associated with them are presented in Table 1.2. In this structure, the rows are representative of *what* aspect of the virtual dogs were studied in each experiment. The top row entitled *Entity* captures findings, where the virtual dog's influence was studied as a whole and mainly focusing on the influence of its presence in a given context. The bottom row entitled *Behavior* captures findings, where the virtual dog's influence was studied with regards to variations in its behavior. The columns are representative of the human, real or virtual, *who* is being focused on as a result of their interaction with a virtual dog. The left column entitled *Self* captures findings that focus on the real human participants, such as their comfort level or proxemics behavior. The right column entitled *Other* captures findings that focus on the other real or virtual human bystanders in a given experiment, such as how likable they were.

	Self		**Other**	
Entity	TS1	Exp 1 Exp 2 Exp 3	TS2	Exp 4
Behavior	TS3	Exp 1 Exp 3	TS4	Exp 1

Table 1.2: Overarching structure of the thesis statements and the chapters detailing the experiments that resulted each thesis statement.

The thesis statements are as follows:

- **[TS1] Entity-Self:** The presence of a virtual dog with dog-like behaviors can induce behavioral and subjective changes within *real human interactants*, including:
  - **[TS1.1]** Increased physical space allocation during virtual dog walking
  - **[TS1.2]** Increased levels of perceived support in front of the virtual dog
  - **[TS1.3]** Enhanced attention guidance-related user experience and reduced fear of missing out
- **[TS2] Entity-Other:** The presence of a virtual dog with dog-like behaviors can induce positive affective changes within *real human interactants* towards *other virtual interactants*.

- **[TS3] Behavior-Self:** The simulated responsiveness of a virtual dog with dog-like behaviors can induce subjective changes within *real human interactants*, including:
  - **[TS3.1]** Enhanced perceptions of copresence
  - **[TS3.2]** Enhanced attention guidance-related user experience and increased preference
- **[TS4] Behavior-Other:** The simulated responsiveness of a virtual dog with dog-like behaviors can induce affective changes within *real human interactants* towards *other real interactants.*

1.4 Contributions

The findings of the human-subjects experiments and the systematic literature in this dissertation present at least the following contributions:

- **Human Effects Category:** I presented the Human Effects category directly inspired by previous human-animal interaction researchers' systematic investigations of the effects of interactions with animals on humans.
- **Research Considerations for Embodied Agents:** I conducted a systematic literature review to identify the primary research considerations for interactions with embodied agents in AR and understand the primary application areas of these agents.
- **Human-Virtual Dog Interaction Research Scope:** I identified the relationship between the Human Effects category and the Research Considerations for embodied agents and utilized these categorization to define a research scope in light of the novelty of previous research in the area of virtual animals and virtual dogs.

- **Virtual Dog Experimental Structure:** Within the Human-Virtual Dog Interaction Research Scope, I identified higher priority research and application areas reflected in the four experiments I conducted that go beyond just the immediate interaction between the real human user and the virtual dog as a whole and presented an expanded analysis on the influence of virtual dogs' presence and behavior in shared spaces with more complex social dynamics with other real and virtual humans.

1.5 Outline

The remainder of this dissertation is organized as follows: **Chapter 2** focuses on the **research background** and describes the effects of real/robotic/virtual dogs and other animals while focusing on the influences real dogs and animals have had on humans (i.e., Human Effects). Later, it expands upon the five primary research areas of embodied AR agents in HMD-based environments (i.e., Research Considerations), and introduces the notion of attention guidance in 360 VR, mechanisms utilized for attention guidance, and the impact of adding acknowledging behaviors to attention guidance mechanisms.

Chapter 3 focuses on the **Research Considerations** mentioned earlier and describes the methodology for the systematic literature review on embodied AR agents in HMD-based environments, presents findings on these agents' primary research and application areas, and discusses emerging trends and potentials for future research.

Chapter 4 focuses on the design of virtual dogs in AR through the **lens of the Physical-Virtual Interactivity Research Consideration** and describes an experiment that studied the influence of a virtual dog's responsiveness to the other real humans on participants' perceptions of the virtual dog and the other real humans who were sharing the physical space with them.

Chapter 5 focuses on virtual dogs as **social support figures** inspired by the Mental and Physical Effects areas of the Human Effects category and describes an experiment that studied the influence of the type and presence of virtual support figures in AR on users' physiological signals and subjective perceptions by comparing a virtual dog to a virtual human and a no support figure condition.

Chapter 6 focuses on virtual dogs as **attention guidance mechanisms in 360-degree experiences** inspired by the Behavior and Expression area under the Human Effects category and describes an experiment that studied virtual dogs compared to other types of attention guidance mechanisms and further explored the influence of acknowledging behaviors for virtual dogs as guides on participants' quality of experience and behavior.

Chapter 7 focuses on virtual dogs as **social priming stimuli** inspired by the social effects area of the Human Effects category and describes an experiment to assess the potential use of virtual dogs as social priming entities and their influence on participants' subjective perceptions and objective behaviors compared to other social priming alternatives such as virtual humans and virtual robots.

Chapter 8 concludes the dissertation, discusses certain limitations, and presents **future research directions** aligned with advances of technology, the Human Effects category, and Research Considerations of embodied IVAs.

CHAPTER 2: BACKGROUND

In this chapter, I will expand upon the four areas presented under the Human Effects category for HDI in Chapter 1, and describe research findings on alternative forms of animals such as robotic or virtual animals. I will present findings on primary research areas of embodied AR agents in HMD-based environments that informed the design of virtual dogs as embodied IVAs. Last, I will introduce the notion of attention guidance in 360 VR and present previous work on the concept of diegesis and acknowledging behaviors as motivations to study virtual dogs for attention guidance.

2.1 Real Dogs

Humans and dogs have shared a historical bond for thousands of years and have assumed a wide range of roles [31]. A few examples are companionship roles as pets or therapy animals, provision of service for individuals with disabilities, and utilizing their sensing abilities in disease detection and search and rescue roles [109, 264, 267]. Various explanations have been provided for the source of humans' inclination towards animals, such as the Biophilia hypothesis, social support theory, or the increasing affectionate behaviors towards infantile or cute faces such as the faces of many cats and dogs [29, 41, 115, 269]. Numerous research contributions aimed at understanding the human-dog relationship from the humans' point of view by focusing on (1) physical, mental, and social effects of interaction with dogs on humans [30, 91, 184, 267], and (2) humans' level of understanding of dogs' behaviors and expressions [40, 137, 245]. The above points, which were captured under the Human Effects category in Chapter 1, will be presented here in more detail. It is important to note that several of the publications in the coming sections include the broader scope of animals and not just dogs; however, in most cases, dogs are the commonly investigated animal [30, 267].

2.1.1 Mental and Physical Effects

Various research contributions document the mental and physical benefits of interactions with animals and, more commonly, dogs. For instance, looking at physical health benefits, Wells [267] presented previous findings in terms of the length, modality, and function of interaction. In shorter-term interactions with familiar or unfamiliar dogs involving actions such as petting and or walking, researchers found and documented evidence of effects, such as decreased heart rate, blood pressure, and increased heart rate reactivity indicating a more relaxed state. [30, 89, 97, 182, 257, 267]. Although some results exist in support of physical health benefits in longer-term interactions, the overall benefits are not yet clear due to mixed findings [267].

Several research contributions focused on studying the mental health benefits of interactions with animals and pets for individuals with and without mental health conditions, such as effects on depression, loneliness, stress, and anxiety [30, 45, 267]. Over the years, many research contributions aimed at capturing the mental and physical health benefits of interactions with animals and pets during stressors through subjective and physiological measures [30].

One of the areas following such approaches is social support studies. Social support has been defined as the experience where one feels valued and cared for in a social relationship with others [246, 269]. Previous research investigated the importance of social support, what and who can act as a social support figure, and the qualities of an entity that are important for being perceived as supportive. Many findings point towards the effectiveness of animals and pets as social support figures compared to human alternatives in the reduction of perceived and/or physiological stress [9, 119, 206]. One of the explanations for the effectiveness of animals and pets as support figures is their ability to provide a sense of security due to their non-judgmental nature [9, 46]. Allen et al. [9] investigated the role of pet, spouses, and friends as social support figures in participants' home environments. Their findings showed lower heart rate reactivity and better task performance in non-evaluative settings such as in front of a pet or alone, emphasizing how the absence of judgment influences the quality of support. The non-judgmental and comforting presence of pets and animals during challenging and stressful tasks were further tested in several studies due to various past findings of the stress-buffering and companionship nature of pets [24, 170, 171, 179]. Kertes et al. [119] investigated the stress-buffering nature of pets on children exposed to stressors, finding reduced perceived stress compared to being alone or in front of their parent. In an exploratory study, Barker et al. [26] identified that interaction with an unfamiliar therapy dog after a stressful task could also decrease the heart rate and cortisol levels similar to interacting with one's pet. Polheber et al. [206] compared the presence and type of support figure (friend, novel dog) following the Trier Social Stress Test [133]. Their results supported the benefits of the novel dog compared to a friend or being alone during social stress by reducing salivary cortisol levels.

Such findings documenting dogs' effectiveness as social support figures opens up opportunities for studying dogs in alternative forms such as virtual dogs amidst the interaction limitations of interacting with real dogs for many individuals in daily life and stressful circumstances.

2.1.2 Social Effects

Previous research suggests that dogs can act as a social catalyst by increasing the chances of socialization with other individuals [30, 171]. The importance of this increased socialization is in its secondary positive influences on humans' well being and psychological health, such as reduction of feelings of isolation and loneliness [171, 266]. In this area, findings have been documented concerning the type of dogs utilized in experimental settings [266], different population groups, and occupations [104, 164, 169, 227, 266].

McNicholas and Collis [169] found that the presence of a dog increased the chance of socialization with other individuals. Interestingly, in a second study, they found that a dog's presence can even increase the number of interactions when the dog handler is not dressed smartly compared to not having a dog at all. Wells [266] compared different factors of social acknowledgment by strangers, such as length of acknowledgment in a study where a female experimenter was either with different dogs, alone, a teddy bear, or a plant. Her findings indicated an increase of social interaction, such as verbal responses and smiles when the different types of dogs were present compared to other conditions indicating dogs' social catalyst effects.

Additionally, research suggests that the presence of dogs with an individual can enhance how other people perceive that individual in terms of factors, such as trust and likeability [30]. One of the benefits of this effect lies in the increase of positive emotions among individuals, which can foster factors, such as social inclusion and cooperativeness [37, 62]. For instance, Colarelli et al. [62] examined the effects of a dog's presence in group tasks and outcomes. In two studies involving group-based and individual tasks, they found that groups that experienced the condition where a real dog was present in the environment seemed to experience a higher degree of factors, such as physical intimacy and trust. Interestingly, these effects have also been observed in circumstances where the stimuli were presented to participants as videos or pictures. For instance, Rossbach and Wilson [218] found that when observing picture stimuli where the presence of a dog and its human companion were varied, participants associated the presence of the dog with attributes such as safety and happiness. Similarly, Schneider and Harley [227] found that when viewing videos of therapists with and without a dog, participants felt more satisfied with the therapist with the dog.

Moreover, looking at the HDI space from a different perspective, research findings on how dog owners perceive their pets revealed that some rely on their dogs' body language and responses when encountered with strangers [164]. Therefore, it may be the case that dog owners might judge strangers based on the reaction of their dogs.

2.1.3 Behavior and Expression

Previous research suggests that dogs can understand certain human verbal and non-verbal communication cues, such as pointing and gazing [43, 111, 255]. Additionally, dogs are capable of communicating with humans through their behavior and expressions [82, 205]. For instance, Miklosi et al. [205] found that dogs are capable of communicating through a behavior called "showing" which "is defined as a communicative action consisting of both a directional component related to an external target and an attention getting component that directs the attention of the perceiver to the informer or sender". In their study, dogs alternated their gaze from the object of interest to their owners and back when the object was hidden. Overall, research suggests that individuals with and without experience with dogs are capable of interpreting dogs' behaviors [40], and perception of dogs' behaviors or emotions from basic facial expressions is not necessarily dependent on previous experience with dogs, and for many behaviors and expressions, both groups make similar assessments [40, 137, 245]. However, experienced and knowledgeable individuals can make more accurate interpretations of more complex expressions [137].

Moreover, many of the roles assumed by dogs, especially service-oriented ones, such as search and rescue, involve various communication signals and guiding elements initiated by dogs with their human handlers communicated through their behaviors and expressions [109, 261]. For instance, in New York Times article [261] the behavior of a cadaver dog upon finding a cue is described as "Panda, a Belgian Malinois with a "sensitive nose," according to her handler, Andrea Pintar, had begun exploring the circular leftovers of a tomb when she suddenly froze, her nose pointed toward a stone burial chest. This was her signal that she had located the scent of human remains."

2.2 Technological Presentations of Animals

Given certain limitations that can restrict individuals from interacting with real dogs and other animals and receiving some of the benefits mentioned in the previous sections, many researchers explored alternative representations of real dogs and animals, such as robotic or virtual animals.

2.2.1 Robotic Dogs and Animals

Over the years, several contributions aimed at understanding how humans perceive robotic animals and documented the effects of robotic animals on individuals. In particular, many focused on use cases of robotic animals for companionship [165, 249, 258], entertainment [117, 172, 215, 263], and animal-assisted therapy [32, 81].

In some of these studies, robotic animals were compared with real animals as a baseline condition [165, 172, 215, 249]. For instance, in a study by Melson et al. [172], children interacted with both a Sony Aibo robot and a real German Shepherd dog in order to understand how they conceptualize the Aibo compared to the real dog. They found that children still treated the Aibo in a dog-like manner, although not as much as the real dog. Thodberg et al. [249] compared a real animal with a seal robot and a cat toy, finding that although both the real animal and the robot were considered to be more interactive compared with the toy, the robot held their attentions for a shorter time span compared to the real animal.

Animal-assisted therapy has also been explored as an application area for robotic animals with *Therabot* as one of the main examples in this category that took into account feedback from clinicians and trauma survivors with capabilities such as touch sensors that could react to the holder's touch [32, 81]. In general, the ability to touch the robotic animals and their physicality seemed to improve feelings of social connection.

Regarding the behavioral patterns of human-robot animal interaction, Kerepesi et al. [117] conducted a study looking at behavioral differences between children and adults, e.g., dog stroking behavior, when interacting with real and robotic dogs. Their results indicated similar behavioral responses towards both the robot and the real dog, such as the duration of stroking behavior of the participants. Also investigating the differences between children and adults voluntary interaction with Aibo during a play session, Weiss et al. [263] was able to classify the reflected emotions of people through their actions in three categories of ignorance, abidance and observation, and interaction, with adults often classified in the first two categories. These findings can provide important insights in the development and research of AR animals specially in the context of companionship.

2.2.2 Virtual Dogs and Animals

Humans have been interacting with virtual animals or animal-like characters while gaming for decades, with the animals occupying different roles such as companions or enemies [176], and this relationship has persisted with the evolution of technology from Tamagotchi pets[1] to popular AR games like Pokemon Go[2] and prototypes aimed at creating experiences where users can raise an AR pet [8]. Some contributions aimed at capturing users motivations for playing pet games [58, 153]. Chesney et al. [58] conducted a survey to assess the companionship affordances of virtual pets in the Nintendogs game compared to real pets, finding that although Nintendogs provided users with companionship it was signifincatly less than real pets. Additionally, Lin et al. [153] found that companionship and relaxation among the motivations for playing pet games and proposed the need for more emotionally responsive virtual animals that can be gradually trained, increasing the users' sense of immersion in the virtual pet games and attachment to the animal.

[1] https://tamagotchi.com/

[2] https://www.pokemongo.com/en-us/

Virtual animals have been shown to have a motivating and encouraging role in educational and health domains for children. Chen et al. [56] found that the inclusion of a personal and class virtual pet through a tablet increases effort towards learning in 11-year old students. Byrne et al. [51] investigated the effects of a virtual pet game compared to a no pet condition and the pet's range of positive/negative behaviors in the eating habits of youth through mobile phones. They found that participants who interacted with the virtual pet capable of both positive and negative behaviors were more likely to change their eating habits positively. In several experiments, Johnsen at al. [108] and Ahn et al. [6, 7] studied the influence of a mixed reality virtual dog on childrens' healthy eating and physical activity where children could interact with the dog and earn tricks for their pet based on their healthy behavior. Their findings suggest that children who interacted with the virtual pet significantly increased their physical activity compared to the control group. Similarly, positive effects of the encouraging nature of virtual animals have been observed with adult populations as well [76, 154]. For instance, Kern et al. [118] created an immersive rehabilitation program using VR technology where participants were accompanied by a virtual dog as their companion and were tasked with leading their companion dog to its home. They found that compared to traditional rehabilitation procedures, their utilized program had positive effects in terms of increasing participants' motivation and reducing their task load.

2.3 Primary Research Areas of Embodied AR Agents in HMD-Based Environments

Embodied agents have been studied and used for decades across a wide range of research and application domains. Their widespread use goes back to the early console and computer games where embodied agents were programmed in the form of non-player characters to exhibit some level of interactive behavior with the user [176]. Most previous research on embodied agents was focused on non-immersive display setups (e.g., TV screens), followed by some examples of work on embodied agents in virtual reality (VR) setups via head-mounted displays (HMDs) or immersive projection technologies [54, 190]. However, only a comparatively small number of publications focused on embodied agents in augmented reality (AR) is tied to the use of optical see-through (OST) or video see-through (VST) head-mounted displays (HMDs). Significant advances have been made in the technology of these AR HMDs over the last few years, including, e.g., the Microsoft HoloLens or Magic Leap One, with advances such as SLAM-based tracking and spatial mapping, which made them attractive for a wider audience [122, 265]. However, dynamic virtual content on AR HMDs, such as embodied agents, still presents many challenges to researchers and practitioners, resulting in critical differences to other forms of agents. Not only do such agents have to be spatially and contextually represented and integrated into existing real-world environments, but they need to provide a means of physical-virtual interactivity, such as showing awareness of real objects as well as exerting influence over the real world. Solving these challenges is a complex task that requires a cross-disciplinary approach [186].

Identifying the primary research areas of embodied AR agents can inform the design of virtual characters and, specifically, virtual dogs in the XR paradigm. Thus, through a systematic review of the literature of 50 publications from 2000 to 2020, five primary research areas were identified for embodied AR agents in HMD-based environments [189]. In Chapter 3 the methodology used for this systematic review is described. In the remainder of this section, these primary areas (i.e., Research Considerations presented in Chapter 1) are introduced and discussed in more detail.

2.3.1 Visual Representation

Out of the 50 publications examined as part of our systematic review of the AR agent literature [189], 15 investigated the effects of AR agents' visual representations, such as the presence of visual embodiment, different appearances, and visual qualities. Most papers researched how the presence of the AR agent's visual embodiment could influence the perception of the agent (9 papers). Five papers studied the AR agent's type, such as, humanoid appearances or non-human ones, such as robots and animals. Four papers focused on the size and proportion of the AR agent, and two covered the visual fidelity or realism of AR agents.

Regarding the impact of an AR agent's visual representation beyond the audio representation, Kim et al. studied the effects of an AR agent's embodiment visually appearing in the user's environment compared to disembodied voice agents in different scenarios—a personal assistant [123], a patient care assistant [131], and a collaborative decision supporter [128]. All the studies in their work showed that the visual representation of the AR agent increased the perceived social presence with and social richness of the agent, and the participants in the personal and patient care assistant scenarios reported experiencing higher level of engagement in the interaction with the visual agents than the voice agents. Miller et al. [178] presented a series of studies related to the social influence of AR agents. One of the studies investigated social facilitation induced by an AR agent's visual presence using anagram tasks, resulting in participants performing the simple task better and the hard task worse when the AR agent was present than when performing the tasks alone. An AR agent's visual representation has been employed for improving the user experience in human-robot interactions. Dragone et al. [80] prototyped a visual AR agent displayed on top of a moving robot as a social interface to communicate with the users, finding that the AR representation helped increase the perceived reliability of the robot and the enjoyment in the interaction. Similarly, Haesler et al. [101] used a visual AR agent to represent an Amazon Echo system, showing that the AR agent's visual representation could help to increase the confidence in the system.

The type of an AR agent's appearance (e.g., human, robot, or animal) has been studied to see its effects on the user's behavior and perception of the agent. Li et al. [151] and Peters et al. [201] conducted user studies investigating the social distance between the participants when interacting with humanoid or robotic agents. They found that the humanoid agent could increase the level of perceived copresence with the human agent than the robot-type agent. Gushima et al. [99] prototyped an AR agent with a jellyfish appearance that could provide daily information to the users as a social notification system, and compared with a human-type agent. While the users preferred the jellyfish for social media content, they wanted a lower-pitched human voice to hear other content, like the news. For instance, in a study by Wang et al. [260], participants liked the miniature humanoid AR agent the most and disliked the full sized humanoid while also comparing with other voice-only and non-humanoid agents.

Visual realism is also an important factor in the AR agent's representation that could influence the user's perception. Mostajeran et al. [181] explored the acceptability of virtual coaches for balance training for older adults. In their study, participants were shown four types of AR agents—realistic and cartoonish male/female avatars. They preferred the realistic male virtual coach over the rest. Reinhardt et al. [213] studied how the different levels of realism in the embodied AR agent's visual representation could affect the user experience. In the study, the more realistic AR agents provided gestural communication cues, such as eye contact and gaze, while the other AR agents (i.e., invisible or wireframe appearance) had no social cues. The realistic AR agents were preferred over the invisible ones, but interestingly the invisible agents were less distracting to users, i.e., they were beneficial when the situation required visual attention as in multitask situations.

2.3.2 Displays & Interfaces

Of the 50 publications examined during our systematic literature review [189], 13 primarily study aspects related to the display modality and interfaces used to view and interact with the AR agents. Out of these display-focused papers, five of them involved system evaluations of prototype systems.

Of the papers that evaluated display modality aspects, twelve primarily investigated differences between users viewing AR agents on AR Displays compared to non-AR displays and platforms, such as physical prototypes [93, 230, 271], or other display modalities [52, 78, 79, 132, 194, 277]. Several interesting conclusions can be drawn from these papers, most notably that users sometimes behave differently in AR versions of the same content than they do in non-AR versions. For example, in the papers by Dow et al. users interact with AR agents in an interactive drama system [78, 79]. Their work found that users were less likely to haphazardly explore their environment or act in a socially unacceptable manner due to not wanting to break social norms. They also note that viewing content in AR modalities rather than non-AR modalities raises the users' expectations of what the system and AR agents are capable of. Gil et al. also investigated differences between AR and non-AR modalities through a study in which children were tasked to read aloud using an AR annotated book and a traditional book [93]. They found that children were more likely to actively participate and exhibit self-based perspectives toward the characters in the story when using the AR system compared to the non-AR.

Another topic is the persistence of an AR agent's influence, after the user has taken off the HMD. Miller et al. [178] studied this concept by asking the participants to either take off their AR HMD or keep it on, and sit in one of two chairs, one of which occupied by an AR agent. They found that both participant groups chose the unoccupied chair more significantly in line with social norms.

Another topic is the effects of AR displays' field of view (FoV). Lee et al. investigated this effect in a study where users viewed an AR agent with either a regular HoloLens one, or one with a restricted visor that allowed the user to only see through the portion of the HMD where virtual content is rendered [143]. This visor reduced the users' FOV of their environment while eliminating disappearance issues that occur when AR agents are larger than the display's FoV. While they hypothesized that eliminating this disappearance issue would affect the users' perception of the AR agent, no significant effects were found. However, users' proxemics behavior were affected, such as slower walking speeds.

We found only one paper somewhat evaluated UIs for interaction with AR agents. In this paper, by Scmeil and Broll, users could interact with an AR agent assistant either via voice commands or a mouse and cursor [225]. Although the two interfaces were not compared formally, user feedback suggested that speech recognition-based input "needs to be improved," but is "very intuitive" to use, while the mouse and cursor style input was also considered "rather feasible" by users.

2.3.3 Physical-Virtual Interactivity

Of the 50 publications examined during our systematic literature review [189], 13 are researching the AR agent's physical-virtual interactivity, covering four areas related to awareness of the physical environment (6 papers), visual coherence in the environment (4 papers), ability to control the environment (4 papers), and haptic feedback (3 papers)—some papers cover multiple subcategories.

AR agents' physical-virtual interactivity research often involves the agent's ability to be aware of and control the surrounding physical environment (i.e., human interlocutors or physical objects). Damian et al. [72] presented an AR agent that could recognize the user's motion/pose, specifically the hands positions, and provide feedback in time to guide certain postures in the given study tasks. Comparing with an AR agent that provides random feedback, the awareness-based feedback made the agent be perceived as more realistic and physically present in the shared space with the users. Kim et al. [121, 132] prototyped an AR agent that could be aware of peripheral events in an AR environment, where the real airflow from a physical fan could influence virtual paper and curtains nearby the agent. Their study showed that the physical-virtual airflow interaction and the AR agent's nonverbal awareness behavior, e.g., looking at the fan or trying to grab the fluttering virtual paper, could increase the perceived copresence with the agent. Kim et al. [129] further studied the impact of more explicit agent behavior exhibiting awareness of the environment. In the study, the AR agent verbally requested help from the participants to move an physical obstacle away, so that she could avoid implausible visual conflict with it, which resulted in positive responses of participants about the AR agent's physical awareness and social presence. Norouzi et al. [191] also showed positive results with a virtual dog that could be aware of the user's feet and behave accordingly, for example, the dog was falling over and whining when it was stepped over. These awareness behaviors of AR agents are normally visually coherent in the environment, for instance, visually plausible occlusions and compliance to the rules in the physical world avoiding physical-virtual conflict. Kim et al. [124] studied the importance of visual coherence using an AR agent with ghost-like behaviors passing through physical obstacles. They found that such visual incoherence could significantly aggravate the AR agent's perceived physicality and animacy.

Regarding the ability to control the environment, Lee et al. [148, 149] developed a tabletop gaming platform enabling an AR agent to move her physical token on the table while playing a board game with the users. In their study, they compared two conditions where the AR agent could move either a physical or a virtual token. They found that the AR agent's ability to control the physical one positively influenced the participants' sense of copresence with it and its perceived ability to move other real objects in the environment, such as small toys. Kim et al. [123] and Heasler et al. [101] employed "smart" objects for AR agents to control the physical world, for example, turn the floor lamp on/off through the the Internet of Things (IoT)-enabled light bulb. They found that such physical interactivity of the AR agent, together with appropriate locomotion, could increase the participants' confidence in the agent's task performance.

The perception of the AR agent's physical interactivity could be through indirect/direct haptics. As a direct way, Okumoto et al. [197] and Sawada et al. [224] presented a dataglove-based interaction with miniature cartoonish AR agents displayed on top of the hands. Different types of haptic feedback for the AR agent were devised, e.g., walking or slipping, and the preliminary evaluation showed that the haptic feedback could make the participants feel the agent's physical presence and encouraged more interactions with it. Lee et al. [143] explored indirect approaches by developing a vibrotactile platform that users could feel a humanoid AR agent's footsteps through a shared floor occupied by the agent and the user. They found that when comparing the AR agent in the haptic footstep feedback condition to those without it, participants subjectively perceived the agent as more realistic and physically co-present, while also adjusting their behavior, such as slowing down, indicating increased hesitance when sensing the footsteps.

2.3.4 Proxemics

The field of proxemics covers the study of space around and between humans, in particular considering interpersonal space, indicating the relative distances between people [103], as well as their correlations with behavior, communication, and interaction. Of the 50 publications examined during our systematic literature review [189], nine studied proxemics, focusing on the spatial relationships between AR agents and users.

The earliest work we found in this area and the only work in the first decade is done by Anabuki et al. [11]. They introduced an anthropomorphic AR agent, Welbo, and through experiments, found that spatial factors could affect users' impressions of Welbo. For example, participants felt more comfortable when Welbo kept some distance and not floated over them. Comfortable social distance between humans and AR agents was researched more frequently later. Aramaki and Murakami [13] reported 70cm based on their experiments using a 18cm cartoonish AR agent. While Peters et al. [201] reported 1.23m as the average comfortable distance for the four types of AR agents they experimented (male, female, small and full-sized robot) and pointed out that the small robot tended to induce a larger distance as people regarded it as being child-like. The different results may be due to the different interaction settings–in the former the agent was standing on the table, while in the latter the agent was placed on the ground and kept mutual gaze with participants.

Interestingly, Bailenson et al. noted that people tended to keep a larger interpersonal distance from virtual agents with mutual gazes [22]. Recently, Lang et al. [141] proposed to position the agent by understanding the scene semantics. They reconstructed 3D models of the real world, detected key objects, and refined the position and orientation of the agent by optimizing a cost function.

Other studied the influences of an AR agent's behavior and spatial factors on participants' proxemics behaviors [151, 193, 194]. Obaid et al. [194] found that people talking to a more distant AR agent would speak louder and be more sensitive to spatial relationships in AR environments than VR environments. Besides direct interactions, Lee et al. [151] looked into a passing-by scenario. They studied people's different behaviors, such as clearance distances, walking speeds and head motions while passing by a virtual or real human that was standing idly, jumping regularly or walking back and forth. They observed that in some cases participants behaved differently with the AR agent compared to the real human, such as longer walking trajectories and slower speeds for the standing conditions. They suggested that this phenomenon might be due to virtual humans being perceived as less predictable in terms of following social norms. Besides AR agents with humanoid appearances, Norouzi et al. [191] studied the influence of an AR dog on people's proxemics behavior with real human bystanders. They found that the AR dog's presence significantly affected participants' proxemics behaviors regardless of the bystander's awareness of the dog.

2.3.5 Behavior & Traits

Of the 50 publications examined during our systematic literature review [189], 14 studied the influence of AR agents' behavior and traits. Twelve papers varied agents' nonverbal behavior, such as facial expression, gaze, posture, and gestures. Only two papers studied the effects of contextual speech on the quality of human-AR agent interaction. For most papers (11 papers) the behavioral variations were intended to enhance the AR agent's sense of physicality (see Section 2.3.3), with a few examples (3 papers) where the influences of different behaviors and traits were the primary focus.

One paper that primarily focused on the development of an AR agent's behavior is by Randhavane et al. [208], aimed at creating a humanoid agent with a friendly demeanor. They developed a "friendliness" model for gait, gesture, and gaze, and utilized this model through an algorithm for generating friendly behaviors. Using this algorithm for an AR agent, they found that interacting with the friendly AR agent increased participants' sense of social and spatial presence compared to a baseline agent. Similarly, Li et al. [151] studied the influence of posture and facial expression of AR agents and their real counterparts, observing that open postures increased the participants' willingness to interact in all conditions. In this area, Obaid et al. [193] simulated culture-specific behaviors in a multi-agent interaction manifested through AR agents' interpersonal distance and gaze behavior.

In several examples, researchers studied the influence of augmenting AR agents with an illusion of physicality by manipulating their behavior, and/or utilizing external tools, such as haptic and IoT-enabled devices. In most cases, AR agents' nonverbal behaviors were varied, such as changes in hand gestures, gaze behavior, and head motion to indicate the AR agent's awareness of its physical environment [72, 121, 124, 129, 132, 143, 191]. A few examples, studied the influence of contextual speech on AR agents' perceived awareness of its environment [72, 129]. Other works focused on the AR agent's physicality by synchronizing its behavior with devices providing haptic feedback, such as vibrations on the floor [143] or through a glove [197, 224] to simulate footsteps or a sliding behavior. Another example of leveraging external mechanisms is the use IoT-enabled devices where researchers studied the influence of AR agents' nonverbal behavior during control of physical objects on the quality of interaction [101, 123].

2.4 Virtual Animals and Attention Guidance

This section details the concept of 360-degree experiences from the lens of prior research on attention guidance and virtual animals, and the benefits of acknowledging behaviors by virtual characters in AR/VR experiences.

2.4.1 *360 Virtual Experience and Attention Guidance*

Recent advances in VR technologies allow users to have more immersive and realistic virtual experiences, for example 360 virtual experiences where the users can have a full 360-degree field of regard (FOR) while navigating or staying at a fixed position in a virtual environment. The majority of 360 virtual experiences involve users being presented with 2D images and videos of real places projected on a virtual sphere around them or a computer-generated 3D virtual environment [150]. The former, with recorded images/videos of the real world can provide immersive experiences with a high sense of realism to users. However, the recorded scenes inherently lack interactivity, e.g., persons in the video cannot natively react to the viewer [236] unless specifically planned [231]. The latter, with 3D computer graphics models can provide such an interactivity with interactive virtual models, and it allows the users to freely move and rotate within the virtual environment. However, rendering high-quality virtual models can be computationally expensive [162].

The need to guide viewers' attention has been addressed in 2D media, such as Hollywood style movies, through the use of techniques like motion and framing manipulation, and increased cuts [159]. Utilizing such techniques leads to a very high *attentional synchrony*—"most viewers look at the same things at the same time." [159]. However such attention guidance approaches may not always work in 360 virtual experiences, where users have the freedom to explore the environment with relatively unrestricted orientation [219, 250]. This freedom can increase the perceptual load, e.g., via necessitating visual searches, and the chance of missing elements or information in the scene or the story [219]. Such information loss could lead viewers to a wrong place in the scene/story (contrary to the desires of the content creators), and in some cases can cause a phenomenon called *"Fear of Missing out"* (FoMo), which is a social anxiety that one might miss or already have missed important parts of the story [163, 219].

2.4.2 Diegetic and Non-diegetic Attentional Mechanisms

Researchers, particularly in cinematic VR film-making, have focused on different techniques to guide viewers' attention and devised taxonomies that studies the characteristics of these techniques and their effects on user experiences [183, 219, 239]. One of the characteristics identified in the taxonomies mentioned above is *diegesis*, which is adopted from film theory [238]. In the context of attention guidance, *diegetic* mechanisms are those that are part of the narrative or the environment, such as utilizing the movements of the characters within that experience [219, 239]. One of the advantages of utilizing characters' motion and other non-verbal behaviors for guidance is that viewers naturally know where to orient based on such cues, and are inclined to follow a character's target of attention [85]. Such methods have been used in film to support *attentional continuity* through multiple cuts [237]. On the other hand, *non-diegetic* mechanisms such as arrows are external to the scene or story, and typically their only function is to guide users' attention to a specific point or direction in the scene or story [219]. The ability of diegetic mechanisms to become part of the experience, compared to non-diegetic ones, has been associated with improvements in user experience, increases in the sense of presence, and higher user preference [53, 183, 239].

In this area, Nielsen et al. conducted a study that compared a non-diegetic attention guidance approach, which controlled the viewer's body orientation, with a diegetic approach that used a firefly to attract the viewer's attention, and the participants reported that the firefly was perceived as more helpful in their story-oriented experience [183]. Cao et al. proposed an automatic method to generate attention guidance metaphors including non-diegetic arrows and diegetic birds [53], and the conducted study utilizing story-oriented content showed that the diegetic guidance encouraged a higher sense of immersion and easily redirected the viewers to the events of interest, compared with the static graphical guidance. Speicher et al. described different attention guidance methods, and conducted a study to investigate the effects of the methods on task performance and user preferences in a virtual environment with 360 videos [239]. Interestingly, they found success with both non-diegetic (object to follow method) and diegetic mechanisms (person to follow method) in terms of user experience and performance.

2.4.3 Virtual Animals and Environment Acknowledgment

Using virtual animals is common and popular in various VR application scenarios from gaming to therapy and social studies [108, 189, 191]. In the context of attention guidance in 360 virtual experiences, virtual animals are appropriate and useful as attractors and/or distractors of attention because their appearances may not be obtrusive, but naturally absorbed in the virtual experience settings, such as birds, fireflies, and butterflies in nature or urban environments. Due to this advantage, prior research has used virtual animals as attention guides, and investigated the effects on the viewer's user experience in different 360 virtual experiences [1, 53, 183, 199, 259, 273].

Virtual animals are particularly beneficial to involve viewers into the virtual experience scenario through their interactive and acknowledging behaviors towards the viewers and the environment—e.g., looking at the viewer or changing the gaze to the target of interest in the environment as diegetic mechanisms. Such acknowledging behaviors have been introduced in many real–virtual human interactions to improve the user's sense of presence in the virtual environment or social presence with a virtual human. Sheikh et al. investigated how different attention-directing techniques influence the viewer's sense of presence in 360 panoramic videos through a user study [231]. The results showed that a character's behavior acknowledging the viewer positively influenced the participants' sense of presence, enjoyment, and immersion. In AR settings, Lee et al. developed a physical-virtual wobbly table, which spans from the user's physical space to a virtual human's virtual space, using a projection screen [145]. They studied how the virtual human's environment-aware behavior towards the user and the wobbly table event, and found effects on the sense of presence and attentional allocation in the interaction. Kim et al. also conducted a user study with a virtual human acknowledging a physical obstacle on her way and asking for help from the participants [130], resulting in a higher social presence and perceived intelligence of the virtual human.

CHAPTER 3: SYSTEMATIC LITERATURE REVIEW OF EMBODIED AUGMENTED REALITY AGENTS IN HMD-BASED ENVIRONMENTS

This chapter presents our methodology to conduct a systematic literature review of embodied agents using AR HMDs from 2000 to 2020. The results of our analysis over this time span details the trends in research and application areas in the field and map out future research directions. This work was instrumental in developing the Human-Virtual Dog Interaction research scope introduced in Section 1.2 and utilized in the remainder of this dissertation to navigate the space for understanding virtual dogs as embodied agents in AR/VR.

This chapter largely incorporates a previous peer-reviewed publication: "A Systematic Literature Review of Embodied Augmented Reality Agents in Head-Mounted Display Environments," authored by Nahal Norouzi, Kangsoo Kim, Gerd Bruder, Austin Erickson, Zubin Choudhary, Yifan Li, and Greg Welch. This work has been presented at and published in the proceedings of the International Conference on Artificial Reality and Telexistence & Eurographics Symposium on Virtual Environments [189].

3.1 Overview

Over the years, various research contributions have focused on understanding and developing embodied virtual characters and agents [187, 190] with the majority of the focus on static setups facilitating 2D desktop-based and projection-based interactions. Advances in AR technology allowed for the realization of embodied agents in 3D rooted in the users' environment. To get a better understanding of potential research considerations for these agents and to identify the primary research areas of the field in the past 20 years, we conducted a systematic literature review [189].

In this work, we captured previous research focusing on understanding and utilizing AR agents in HMD-based environments, and set out to answer the following research questions:

- **RQ1:** What are the primary research categories of embodied agents using AR HMDs?
- **RQ2:** What are the common roles where embodied agents are utilized or envisioned using AR HMDs?
- **RQ3:** How have AR agents evolved over the years in terms of their appearance and utilized technology?
- **RQ4:** What areas of AR agent research can benefit from more focused future attention?

Through the structured iterative methodology described next, we make the following contributions: we conducted an in-depth review of 50 directly related papers from 2000 to 2020, focusing on papers that reported on user studies aiming to improve our understanding of interactive agents in AR HMD environments or their utilization in specific applications. We identified common research and application areas of AR agents through a structured iterative process, present research trends, and gaps, and share insights on future directions.

3.2 Methodology

We conducted a systematic literature review by adopting several of the core steps of the PRISMA method [152]. This section, details the steps taken to complete our systematic review.

Our goal for this literature review was to capture previous work that studied embodied AR agents in HMD environments or leveraged them for a specific application. To ensure that a broad scope of related work is identified, we came up with the keywords shown in Table 3.1 that include our primary criteria of field, agent, and device. We applied these search terms to the four digital libraries of the Association for Computing Machinery (ACM), Institute of Electrical and Electronics Engineers (IEEE), Web of Science (WoS), and ScienceDirect (SD). Our search process was applied to all fields within each library and was restricted to previous work published in English from 2000 to 2020. The search was completed on August 2–3, 2020. Figure 3.1 shows the number of papers at different stages of our search, screening, tagging and reviewing processes.

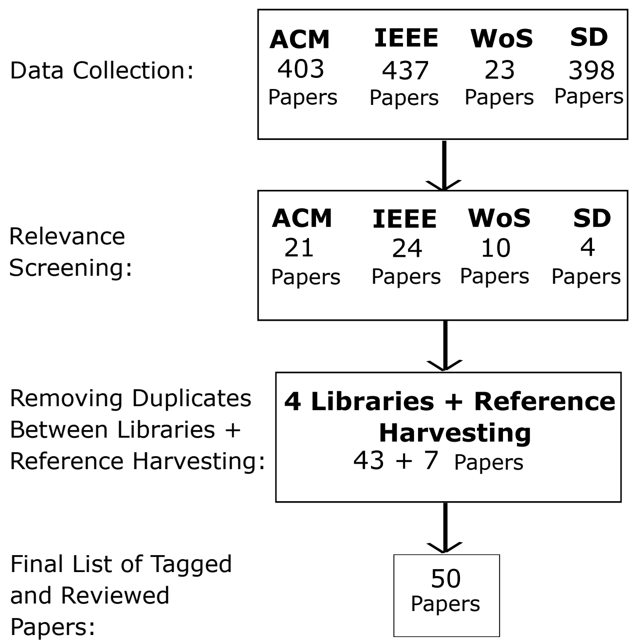


Figure 3.1: Diagram of our systematic review process.

Due to restrictions in the number of search terms and Boolean operators allowed for the IEEE and SD digital libraries, we adjusted our search strategy for these specific libraries. For IEEE, to adhere to the maximum of 40 search terms and 15 search terms per clause rule, we repeated our search three times so that every time less than 15 search terms were used for the agent-specific ones (see Table 3.1), since the agent clause was the only one with more than 15 search terms.

Since SD only allows for use of 8 Boolean operators, we did not use the device-specific search terms (see Table 3.1) and for the remainder of our search terms followed a similar approach as for the IEEE library by dividing the agent-specific search terms to make sure every time only 8 Boolean operators were used. These steps resulted in 403 papers in ACM, 437 papers in IEEE, 23 papers in WoS, and 398 papers in SD.

Search Criteria	**Search Terms**
Field	(”augmented reality” OR ”mixed reality”)
Agent	AND (”virtual agent” OR ”virtual agents” OR ”virtual character” OR ”virtual characters” OR ”virtual human” OR ”virtual humans” OR ”virtual animal” OR ”virtual animals” OR ”virtual people” OR ”virtual person” OR ”virtual persons” OR ”virtual crowd” OR ”virtual crowds” OR ”virtual audience” OR ”virtual audiences”)
Device	AND (”head-mounted display” OR ”head-mounted displays” OR HMD OR HMDs OR headset OR headsets OR hololens OR ”magic leap” OR vive OR oculus)

Table 3.1: Search terms used to identify related papers in this literature survey.

In the scope of this review, we focused on AR agents as embodied entities presented on an AR HMD that are capable of facilitating a two-way interaction with the user through one or multiple modalities, and used this definition during the scanning phase. Thus, papers that studied AR agents or utilized them in specific applications through user studies in HMD-based environments were considered relevant. We used the following exclusion criteria to remove publications that were not in line with our goals:

- Work that did not contribute to the understanding or advancement of AR agents using HMDs.
- Work that did not include a user study.
- Work that did not specify the interface or modalities for an interactive experience between users and AR agents.
- Work that was published as a book, book chapter, or thesis.

The lead author of this chapter scanned all papers using the exclusion criteria described above. This process resulted in 43 relevant publications. After this first top-down phase, we then performed an additional bottom-up literature search phase, often called reference harvesting [155], in which we searched the related work sections of the 43 papers and added 7 more publications to our list. The in-depth review of these 50 papers are presented in Section 2.3. We further collected the papers' citation counts via Google Scholar on August 26, 2020 and calculated the average citation count (ACC) for all papers, indicating the average number of citations per year.

To understand the scope of research and applications focused on AR agents and the type of agents and HMDs most commonly used, we determined the following tags during the review phase:

- **Research Category** of AR agents,
- **Application Area** of AR agents (tested or intended),
- **Appearance** of AR agents,
- **HMD Type**.

Section 3.3 details the identification/tagging process of our research categories and application fields.. Five authors of this chapter participated in the identification/tagging process. Multiple tags per paper were allowed. To ensure that all members had a similar understanding of the different tags, five papers were picked randomly from the initial list of 43 papers and tagged by everyone. Later, we reviewed the tags assigned by everyone for the aforementioned five papers, discussed them together, and refined our tags accordingly. After this process, the papers were shared among our team, tagged, and uncertainties were discussed in a separate session.

Afterward, we divided the 50 papers based on their research category and assigned each category to a team member to provide a more in-depth view of AR agents within that area of research.

Members were asked to give priority to publications with an ACC higher than 3, which is in line with the ACC of the 50 papers ($M = 3.28$), and also all papers from 2017 to 2020 regardless of their ACC. We did not consider ACC as a criterion for papers published after 2017, as they had less time to be cited, and they included more than 50% of the total number of our papers.

3.3 Research and Application Areas

In a top-down process, we used previous relevant literature reviews on the topics of augmented reality [74, 122], intelligent virtual agents [190], and social presence [196] to come up with preliminary tags for research categories and application areas. Later, after reviewing the 50 relevant publications, we utilized a bottom-up approach to refine and finalize our tags. For both research and application categories some papers focused on more than one category of research or application area. In these cases, the papers were represented with multiple tags. Hence, the number of tags exceeds the total number of papers.

To identify a paper's application area, we used both the tested application in the paper and the AR agent's motivated use case, which influenced the paper's research questions and the task type the AR agent was involved in during the user study. For instance, papers that motivated their AR agent for general interactions but explored the human-agent interaction in a collaborative/assistive task, or papers that motivated their AR agent for collaborative/assistive roles but examined them in general tasks were tagged in the collaborative-assistive application area. Our research categories are defined as below:

- **Visual Representation:** work that investigates the visual qualities of AR agents and the importance of this modality.

- **Displays and Interfaces:** work exploring the effects of display mediums and interfaces for interacting with AR agents.

- **Physical-Virtual Interactivity:** work that investigates the impact of augmenting AR agents to be interactive with the surrounding physical environments.

- **Proxemics:** work that investigates the spatial relationships between AR agents and human users.

- **Behavior and Traits:** work that investigates the influence of AR agents' verbal and nonverbal behavior, personality traits, and characteristics on human-AR agent interaction.

Additionally to these research categories, we tagged the publications by application areas. Since not all publications focused on an application, the number of these tags differ from the total number of publications. Our application areas are defined as:

- **Assistive/Collaborative:** work utilizing AR agents in assistive roles or studied their potential as collaborative partners, such as personal assistants, exercise coaches, or guiding roles.

- **Entertainment and Interactive Media:** work utilizing AR agents for more interactive entertainment-oriented experiences.

- **Healthcare:** work utilizing AR agents to enhance the health of specific populations, or as a teaching tool for healthcare students or professionals.

- **Training:** work utilizing AR agents for training specific skills.

3.4 High-Level Analysis

In this section, we provide a high-level overview of the 50 papers in terms of HMD type, AR agent type, ACC, research category, and application area. Figures 3.2 and 3.3 illustrate the trends for numbers of papers and ACCs in the field.

3.4.1 General Overview

Overall, we identified 50 papers that studied AR agents or utilized them for specific applications in HMD environments and assessed AR agents' features and/or their system through user studies. The majority of these papers are published from 2017 onward ($\%58$), which is in line with the increased availability and reliability of consumer commercial-off-the-shelf (COTS) or developer edition HMDs. This trend is partly supported by the ubiquity and popularity of voice-only assistants [157, 207] presenting new opportunities for utilizing AR technology to investigate the influence of embodiment and its implications for such entities.

We classified the HMD types based on the hardware specifications or the system descriptions provided by the papers, and marked those without any specifications or clear descriptions as *unspecified*. Figure 3.2 shows the different types of HMDs used over the years. OST-HMDs were more common (30 papers) specially in the past four years due to the increasing availability of such devices, with Microsoft HoloLens more commonly used than other devices (23 papers). 19 papers utilized VST-HMDs, most of which were used before 2018.

To address our third research question **(RQ3)**, we explored the different appearances for realizing embodied AR agents. As inspired by robotics literature, the agent's appearance can influence the quality of interaction in terms of emotional connection and trust [234]. As expected, the majority of the AR agents studied were designed to have a human-like appearance (39 papers), with fewer

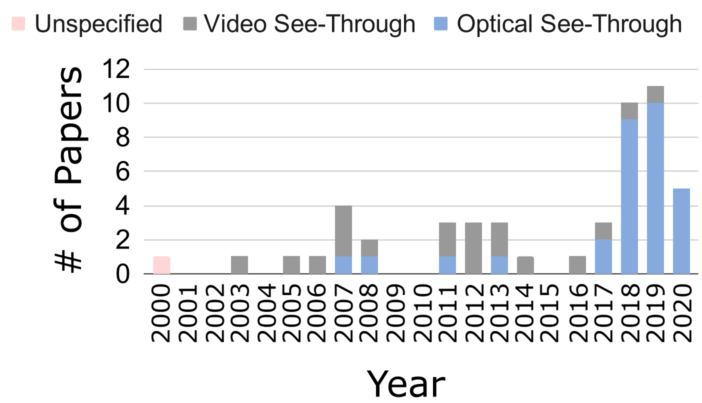
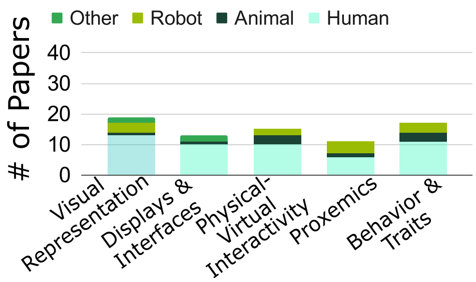
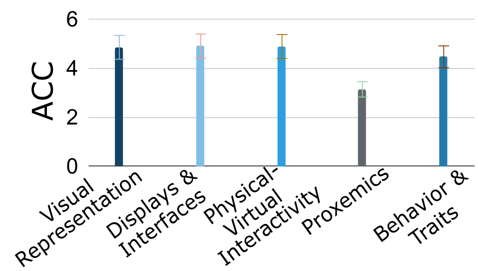


Figure 3.2: Types of HMDs utilized in AR agent research per year.

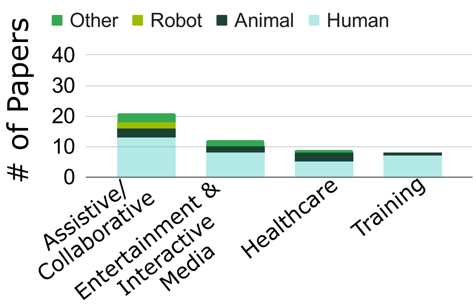
examples of AR agents embodied as animals (9 papers) or robots (6 papers). 5 Papers used AR agents embodied as cartoon characters, monsters, or anthropomorphic objects, such as an anthropomorphic sun, which we tagged as *other* (see Figure 3.3e). Figures 3.3a and c show AR agent types based on research category and application area. Humanoid AR agents were more commonly used in all research categories and application areas. Interestingly, except humanoid AR agents, animal-like AR agents were the only type studied among all research categories and application areas. Some papers utilized more than one type of AR agent; therefore, the total number of AR agent types is higher than the number of papers. Accordingly, papers with humanoid AR agents have a higher ACC (3.94), followed, by other (2.51), animals (2.19), and robots (1.83) (see Figure 3.3f). Although AR agents with appearances tagged as other were less common, they lend they higher ACC to two recent papers where in one the AR agent is embodied as a minion [16] and in the other as a smart home device [260].



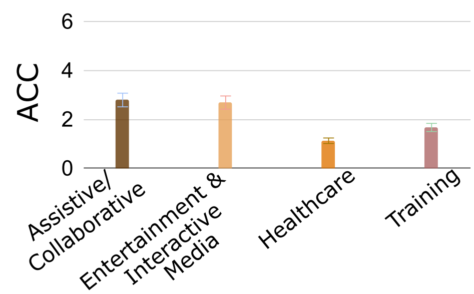
(a) Research Category



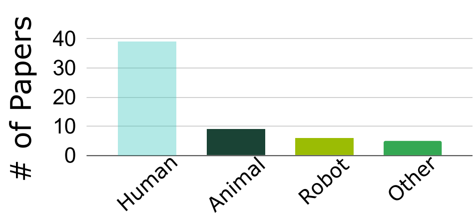
(b) Research Category



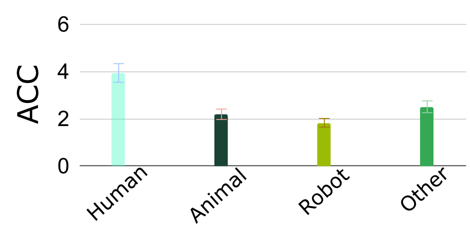
(c) Application Area



(d) Application Area



(e) AR Agent Type



(f) AR Agent Type

Figure 3.3: Number of papers (left column) and ACC (right column) of the reviewed papers plotted against the different (a & b) research categories, (c & d) application areas, and (e & f) AR agent types.

3.4.2 Research and Application

Out of our 50 reviewed papers, 33 either focused on a specific application or motivated their use of AR agents and/or their research questions to address the needs of a certain application. The assistive/collaborative area was the most popular (18 papers), followed by entertainment and interactive media (10 papers), healthcare (8 papers), and training (6 papers). The assistive/collaborative AR agents were utilized or envisioned as personal assistants, lab assistants, navigation guides, virtual coaches, or collaborated with users in search or decision making tasks. Such use cases are in line with current uses of intelligent personal assistants, such as Amazon Alexa, Apple Siri, Google Home Assistant, or those envisioned as guides and companions, such as Magic Leap Mica. This area has been cited more frequently than others with an ACC of 2.79, followed closely by the entertainment and Interactive media area (2.69), training (1.67), and healthcare (1.12) (see Figure 3.3d).

A total of 38 of our 50 papers focused on understanding specific research categories with regards to AR agents and user interactions with systems utilizing AR agents. The remaining 12 papers are not represented here due to their focus on understanding the efficacy of their application-specific prototypes without comparative evaluations. The visual representation of AR agents received the highest attention (15 papers), followed by behavior and traits (14 papers), display and interfaces (13 papers), physical-virtual interactivity (13 papers), and proxemics (9 papers). Research on the influences of display and interfaces received the highest ACC (4.9), followed by physical-virtual interactivity (4.89), visual representation (4.85) behavior and traits (4.47), and proxemics (3.14) (see Figure 3.3b).

3.5 Emerging Trends and Future Directions

In this section, we present identified trends in the context of common roles where embodied AR agents were utilized or envisioned to address **RQ2**. We propose open research areas inspired by previous trends in other domains of augmented reality and robotics research in response to **RQ4**. Exploring the proposed areas does not necessarily depend on the quality of the state of the art technology as in many cases Wizard of Oz [71] setups can be utilized.

[RQ2] AR Agents in Assistive/Collaborative Roles:

In recent years, corresponding to increased commercial popularity of voice-based assistants such as Amazon Alexa or Google Home Assistant [158], the notion of embodied agents has received increasing attention [186]. For example, AR HMDs have been used to provide a 3D body for such assistants, with results indicating benefits for assistive/collaborative roles [123, 128, 131, 181, 213, 260]. In this area, an increasing presence of IoT-enabled devices has presented research opportunities for AR assistants capable of controlling various appliances through physically and contextually coherent behavior, with findings supporting the idea that such behaviors enhance a user's confidence in the AR assistants [101, 123]. These findings, together with the anticipated increasing integration of IoT-enabled "smart" devices in everyday life [209] give rise to new research questions related to networked smart sensing and actuating modules, e.g., in smart home environments, as a mechanism for enhancing an AR agent's awareness and understanding of the physical environment.

[RQ2] AR Agents in Other Identified Application Areas:

With respect to the application areas that arose during our literature survey (see Section 3.3), most papers focused on the use of AR agents in an assistive/collaborative role. Comparatively less research has been carried out in other application areas, such as entertainment and interactive media. This may be partly due to current limitations of AR HMD technologies, e.g., their ergonomics and lighting requirements [83], and their limited availability compared to the ubiquity of smartphones as an alternative platform for AR apps (e.g., Pokemon Go). In other application areas, such as healthcare and training, less research might be due to the cost and logistical difficulties associated with AR HMDs with more reliance on other mediums such as spatial augmented reality (SAR) or other displays [65–67]. However, with the increasing availability of inexpensive COTS AR HMDs such as the Microsoft HoloLens or Magic Leap One, we anticipate a steadily increasing range of applications that might benefit from AR agents in single and multi-user experiences. Through our literature survey, we are seeing an increase in the number of studies that evaluate the capabilities of AR HMDs, AR agents, and their effects on the users (see Section 3.4). This trend is likely to continue into the foreseeable future as newer generation HMDs with extended feature sets (e.g., embedded hand tracking or eye tracking) present opportunities to develop new knowledge about interactions with AR agents.

[RQ4] AR Agents as Companions:

During our review, we noted a few examples that motivated or presented AR agents associated with companionship [55, 191]. Previous research investigated the use of robots or virtual agents in other platforms (e.g., desktop-based) as companions or therapy partners with promising results [32, 73, 222, 254]. With findings supporting the importance of long-term interactions for artificial pets and social robots [139, 161], we speculate that some limiting factors of current AR

HMDs, such as limited availability, heavy weight, and small FoV might have affected the potential use of this technology for researching AR agents in companionship and therapeutic roles. However, with advances in technology and the growing availability of AR HMDs, we foresee new research opportunities for AR agents in this domain for reasons such as the potential for pervasive presence in our physical environment, their anticipated capacity for spatial and contextual understanding, and their flexibility in embodying different types and appearances. Such factors pose new research questions on the extent of their influence compared to other technological companions, as the technology itself evolves and becomes more readily available.

[RQ4] AR Agents and Multimodal Communication:

As research on AR agents in HMD environments grows in different areas (see Section 3.4) where such agents could become embedded into our professional settings as well as our daily social lives, new questions arise with regards to how such agents should communicate, move, and behave such that they are compatible with other social entities. Depending on the interaction context in both AR and non-AR environments, we see an emerging trend in the way that voice-based communication is enhanced with other modalities that can complement speech interactions [128, 232, 260], although we did not identify examples solely relying on nonverbal communication, certain real-life circumstances where speech is not a convenient communication mechanism, present new research questions regarding the effectiveness of AR agents' nonverbal behavior communication. For instance, in environments with high ambient noise, users and AR agents may rely on pointing or gazing towards objects for communication, and a plethora of other possible social signals. We further observed an increasing number of works related to proxemics with AR agents in social spaces, emphasizing that such agents need to move through social spaces in a natural way, which includes maintaining an acceptable social distance. We believe that more proxemics research is necessary to understand the spatial relationship between users and AR agents in different social situations.

[RQ4] AR Agents and Influence of Personality and Empathy:

In line with previous non-AR research focused on agents' personalities and emotions, we identified a few examples where the primary research focus was to understand the impact of such aspects, like friendliness and openness. [151, 193, 208]. As past research suggests that interactions with AR agents can have different influences on users on aspects such as social presence, and involvement [78, 132, 277] new research questions arise as to the extent of AR agents' personality influence in different interaction contexts. Also, borrowing from previous literature in AR/VR human-human collaboration studying ways of transferring users' emotions or perspectives to promote empathy [166,204], and the recent examples identified in our work of human-AR agent collaborations [128, 260], we predict new research opportunities in realizing AR agent's capable of empathy and perspective-taking by understanding a user's facial expression, tone, or situational context.

3.6 Conclusion

In this chapter, we presented a systematic literature review of previous research on interactive embodied AR agents presented on HMDs. We provided detailed reviews of 50 related papers covering the years from 2000 to 2020. In particular, we discussed papers that aimed at improving our understanding of AR agents or their utilization in application domains. We identified common research and application areas of AR agents, presented research trends and gaps, and shared insights on future directions, which may help to structure and foster future research in this emerging field.

CHAPTER 4: DESIGN OF VIRTUAL DOGS IN AUGMENTED REALITY

This chapter presents a human-subjects study focused on improving our understanding of behaviors and characteristics of virtual dogs in AR and their interactions with other people. In this study, we utilize the notion of physical-virtual interactivity to simulate the virtual dog's responsiveness to other real humans identified as one of the Research Considerations in our systematic literature review [189].

The thesis statements supported by this chapter are as follows:

- **[TS1] Entity-Self:** The presence of a virtual dog with dog-like behaviors can induce behavioral changes within *real human interactants*, including:
  - **[TS1.1]** Increased physical space allocation during virtual dog walking
- **[TS3] Behavior-Self:** The simulated responsiveness of a virtual dog with dog-like behaviors can induce subjective changes within *real human interactants*, including:
  - **[TS3.1]** Enhanced perceptions of copresence
- **[TS4] Behavior-Other:** The simulated responsiveness of a virtual dog with dog-like behaviors can induce affective changes within *real human interactants* towards *other real interactants.*

This chapter largely incorporates a previous peer-reviewed publication: "Walking Your Virtual Dog: Analysis of Awareness and Proxemics with Simulated Support Animals in Augmented Reality," authored by Nahal Norouzi, Kangsoo Kim, Myungho Lee, Ryan Schubert, Austin Erickson, Jeremy Bailenson, Gerd Bruder, and Greg Welch. This work has been presented at and published in the proceedings of the IEEE International Symposium on Mixed and Augmented Reality [192].

4.1 Overview

Virtual animals in AR are particularly interesting since they are not limited by a physical manifestation in the real world—they could exist virtually anywhere and appear at any time depending on users' needs. Additionally, as real animals provide various health benefits to humans [30, 267], it is valuable to explore the domain of virtual animals as they may be able to contribute to human health as well. However, before virtual animals are studied in an applied context, it is important to understand human perception and behavior with respect to human-dog interactions. We conducted a human-subjects study taking design factors into account that align with some of the identified primary research areas of embodied AR agents in HMD-based environments [189]. In this study, we intended to provide answers for the following research questions:

- Q1 How does walking an AR dog change its owner's locomotion behavior and proxemics in the presence of another person?
- Q2 How do the AR dog's awareness and behavior with respect to a person in the physical environment affect its owner's perception of the dog and that person?
- Q3 How does another person's apparent ability to see the AR dog affect the owner's perception and behavior with respect to the dog and that person?

The findings of this chapter support **TS1** by showing that the presence of the AR companion dog changed participants' locomation behavior during a dog-walking task. We found support for **TS3** and **TS4**, as the simulated responsiveness of the virtual dog influenced participants' perceptions of the virtual dog and the other real human bystanders involved in the experiment by first enhancing their sense of copresence with the virtual dog and second reducing the level of positive affect towards the real human bystanders.

4.2 Experiment

Here we describe the experiment we conducted to investigate the effects of an AR dog on human perception and behavior, including locomotion and proxemics, in the presence of another person.

4.2.1 Participants

We recruited 21 participants (eight females, thirteen males) from the graduate and undergraduate student community of the University of Central Florida. Our experimental procedure and recruitment of participants were approved by the institutional review board (IRB) of our university under protocol number SBE-18-14558. All participants had normal or corrected vision and all of them were naïve with respect to the study and goals of the experiment. 14 participants owned pets, all of which were either cats or dogs. We asked all participants about any past experience interacting with virtual pets/animals, and 13 reported that they had interacted with virtual pets/animals in a gaming context before. 12 of these participants categorized the roles of the virtual animals as non-player characters, such as their companion or an enemy to be defeated in the game. On a 7-point Likert scale (1 = no familiarity, 7 = high familiarity), we asked our participants to rate their level of familiarity with computers (M=5.38), VR (M=4.71), AR (M=3.42), virtual living/sentient entities (M=3.04) and virtual non-living/non-sentient entities (M=3.38). Four participants had to be excluded from our analysis and results due to technical issues (i.e., tracking loss and unrecoverable data) with the HoloLens HMD that occurred during the experiment, and two additional participants were excluded because they did not follow the experiment instructions. All participants gave their informed consent and received monetary compensation of $15 for taking part in this experiment.

4.2.2 Material

In this section, we describe the stimulus and physical setup that we used in the experiment.

4.2.2.1 AR Dog's Appearance and Control

We used a rigged Beagle dog[1] model that was animated and rendered via the Unity graphics engine (version 2018.2.7f1). We chose a dog as the virtual animal to be used in this study due to the fact that dogs are one of the oldest and most common domestic animals [64, 223]; although cats are also common as pets, we felt that dogs typically exhibit significantly more consistent, responsive, and predictable behaviors (as used in the study and described below) compared to cats.

The dog model included four different textures (corresponding to different visual appearances) and several animations, so we were able to change the color pattern of the dog and control its behavior, which included eating, drinking, digging, walking, barking, sitting, resting, scratching, sniffing, and falling over (see Figure 4.1 and Figure 4.2(a–e)). We controlled the AR dog's walking behavior by specifying a 3D locomotion target in Unity which the dog would then walk towards. A collision-based approach then detected when the dog had arrived at that location so it would stop walking. For the parts of the study where participants were expected to walk with the dog, the dog's locomotion target was dynamically updated to a location at the participant's left or right side as the participant moved (see Figure 4.3). In this way, the AR dog naturally followed participants as they walked. The AR dog's walking speed was capped at 0.5 m/s, which we used as a reasonable speed for a simulated dog of this size and age [95, 221, 244]. For auditory feedback, a panting sound was intermittently played the whole time except during some of the dog's animations that inherently included sounds, such as barking or sniffing. The dog was remotely controlled by a

[1] https://assetstore.unity.com/packages/3d/characters/animals/dog-beagle-70832

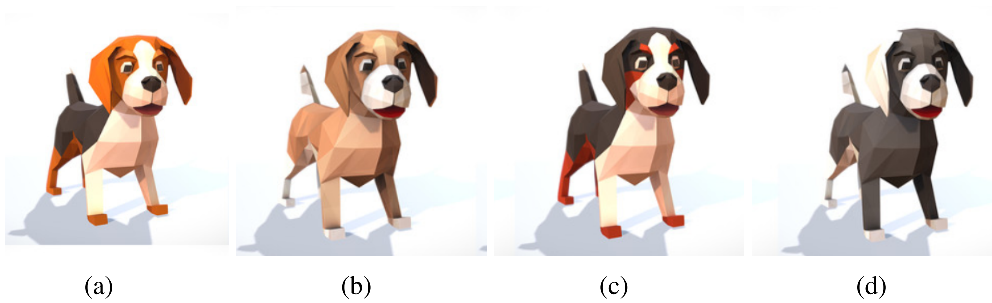


Figure 4.1: Snapshots of the four different appearances that participants chose for the AR dog.

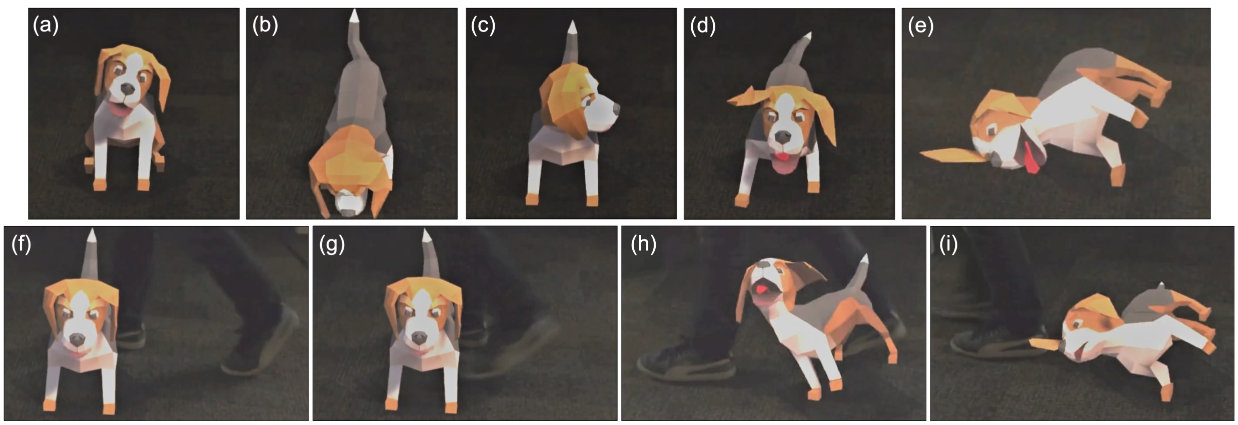


Figure 4.2: Photos illustrating our AR dog behavior animations: (a) idle seating, (b) sniffing, (c) idle standing, (d) barking, and (e) falling over. A sequence of photos illustrating a collision of the AR dog and a real human: (f–i) the dog is falling over when a real human walks over it. All photos were taken through a Microsoft HoloLens.

human experimenter using a separate computer, hidden from view of the participants, using a human-in-the-loop mechanism following the *Wizard of Oz* paradigm. A graphical user interface (GUI) enabled the experimenter to trigger the different dog behaviors in real time as the participants were interacting with the AR dog.

4.2.2.2 Human Confederates

In order to test the effects of other people in the physical environment on the participants' perception and behavior with respect to the AR dog, we included human confederates (co-experimenters) and we will use the term confederates in the rest of the document for simplicity. We recruited four of our research group members as confederates in this study. Each pair of confederates was chosen to be as similar as possible, and which confederates the participants saw over the course of the study was randomized. Each confederate was trained on how to perform a set of standardized behaviors with respect to the virtual dog (see Section 4.2.3.1).

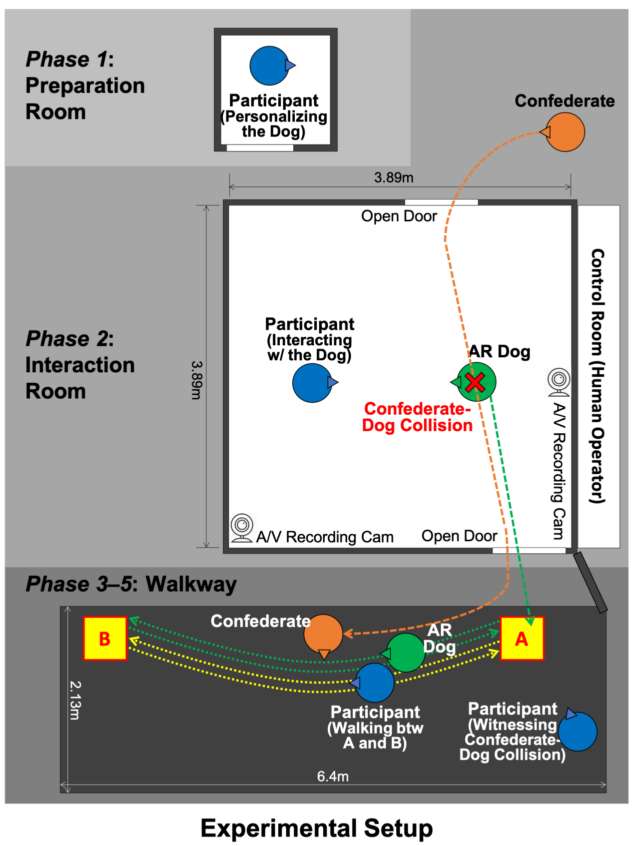


Figure 4.3: Top-down illustration of the laboratory space and physical setup used in the experiment.

4.2.2.3 Physical Setup

For the experiment, we used a part of our laboratory dedicated for human-subject studies. Figure 4.3 shows an illustration of the physical setup that we used for this experiment.

A small booth was used as a preparation room where participants could have a quiet, isolated space to give their informed consent, receive study descriptions and instructions from the experimenter, and answer the questionnaires that we prepared for them.

For the interaction with the AR dog in which participants gave commands to the dog and watched its responsive behaviors, we prepared a 3.89 m×3.89 m immersive CAVE-like environment with four projection walls and two doors facing each other. Regular office-like images were projected onto the walls to make the participants feel like they were in an ordinary office room. We also prepared a 6.4 m×2.13 m walkway platform outside the interaction room, which we used to measure the participants' walking behaviors with/without the dog, which are described in Section 4.3.1. We mounted two webcams for video and audio recordings on the walls of the interaction room as depicted in Figure 4.3, and participants were recorded throughout the experiment.

As described in Section 4.2.2.1, the experimenter was controlling the AR dog using a GUI from the controller area behind the interaction room, so that participants would feel that the dog was responding naturally to their commands.

We used two Microsoft HoloLens optical see-through HMDs for this experiment. One of them was worn by the participant at all times, and the other was sometimes worn by a confederate depending on the experimental condition. Participants moved around the experimental space according to the study procedure, which is described in detail in Section 4.2.3.2.

4.2.3 Method

4.2.3.1 Study Design

We used a 2×2 mixed-factorial design for our experiment. The two independent variables were related to the awareness and behavior of (1) the human confederate and (2) the AR dog:

- **Confederate**: The confederate wore a HoloLens and expressed awareness of the AR dog before walking over it, or exhibited unawareness and did not wear a HoloLens.
- **AR Dog**: The AR dog showed awareness and responded to the collision with the confederate's foot by falling over when the confederate walked over the dog, or expressed unawareness of the confederate's foot passing through it.

The two levels of awareness and behavior for the confederate were as follows: Either the confederate was not wearing an HMD and walked over the dog, or the confederate was wearing an HMD such that the AR dog could be plausibly visible to him and further expressed awareness by saying out loud *"Oh, there's a dog"* while looking at the dog just prior to walking over it.

We depicted two levels of awareness and behavior for the AR dog. During the moment of collision between the confederate's foot and the AR dog, either the dog showed no reaction and continued with its current idle animation or the idle animation was interrupted by a new animation showing the dog falling over accompanied by subtle whining auditory feedback.

We chose the confederate's awareness and behavior as a within-subjects factor, since we considered these typical occurrences for different people and real use situations for an AR dog, and to also control for the possibility of learning effects impacting participants' perceptions. In contrast, we decided to treat the dog's awareness and reaction to the collision as a between-subjects factor, since these conditions are more in line with design choices or technological limitations between different AR dog realizations. Separately, we predicted that individual differences play a more important role in the case of confederate's awareness compared to the AR Dog's awareness.

Throughout this chapter, we adopted specific abbreviations and a naming scheme to communicate our conditions. **C** for the term *condition*, **A** for depiction of the *aware behavior*, and **U** for depiction of the *unaware behavior* by either the confederate or the AR dog. Also, since we are varying the awareness levels of both confederate and the AR dog, the left subscript in each condition indicates the awareness level of the confederate and the right subscript is for the AR dog, e.g., $\mathbf{C_{A,U}}$ means that the confederate is aware but the dog is unaware. We tested the following four conditions:

- $\mathbf{C_{A,A}}$: The confederate wearing a HoloLens was *aware* of the dog, and the dog was *aware* of and reacted to the collision with the confederate's foot.
- $\mathbf{C_{U,A}}$: The confederate not wearing a HoloLens was *unaware* of the dog, but the dog was *aware* of and reacted to the collision with the confederate's foot.
- $\mathbf{C_{A,U}}$: The confederate wearing a HoloLens was *aware* of the dog, but the dog was *unaware* of the collision with the confederate and the foot passed through the dog without reaction.
- $\mathbf{C_{U,U}}$: The confederate not wearing a HoloLens was *unaware* of the dog, and the dog was *unaware* of the collision with the confederate and the foot passed through the dog without reaction.

The assignment of confederates to conditions, the appearance of aware vs. unaware confederate, and the order of conditions were randomized between participants.

4.2.3.2 *Procedure*

After reading a consent form and agreeing to take part in the study, participants were given a brief introduction of the study, and filled out a pre-experiment questionnaire, followed by five phases:

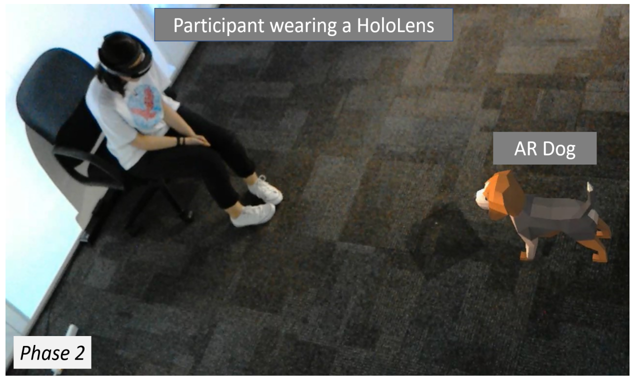
- **Phase 1 [Dog Personalization]**: In the first phase, participants saw a computer graphics representation of a Beagle dog on a computer screen and were asked to personalize their new dog by choosing its appearance and naming it. Figure 4.1 shows the different available appearances for the AR dog.
- **Phase 2 [Play Session]**: In the second phase, participants were guided to a chair in the interaction room and asked to wear the HoloLens so that they could see their AR dog sitting on the floor in front of them. Before leaving the room, the experimenter handed them a command sheet on which eight verbal commands were listed, such as “sit” and “bark,” which the participant could use to interact with the dog. Participants were then given three minutes to interact and play with their AR dog by issuing commands of their choice to the dog and watching the dog’s consequent behaviors Figure 4.4(a) shows our setup for Phase 2.
- **Phase 3 [Witnessing Collision]**: After the interaction with their AR dog, participants left the dog behind and were guided by the experimenter to a predefined location on the walkway outside the interaction room. Participants could still see their AR dog that they left inside the interaction room, and they were asked to keep an eye on their dog. At this moment, we triggered the condition-dependent behavior between the confederate and the AR dog. The confederate entered the interaction room through a door (placed above in Figure 4.3), walked over the AR dog (i.e., toppled it over or passed right through it depending on the condition), and exited through another door toward the assigned spot on the walkway. The confederate was either wearing a HoloLens and exhibited awareness of the dog or not wear-

ing a HoloLens and not exhibiting awareness (see Section 4.2.3). The path walked by the confederate was the same in both cases.

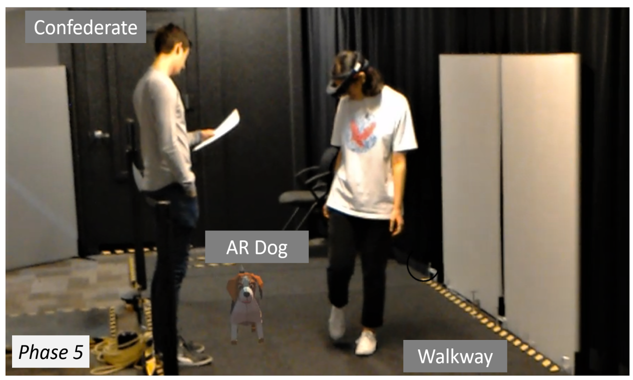
- **Phase 4 [Walking without AR Dog]**: Once the confederate stood on the assigned spot on the walkway (see Figure 4.3), participants were asked to stand on the start location A, walk towards location B, and then return to location A. Participants were informed that this was necessary for calibration purposes. This part allowed us to compare their walking behavior with the AR dog to a baseline of their natural walking behavior when their dog was not with them.

- **Phase 5 [Walking with AR Dog]**: After walking alone on the walkway, participants were asked to call their AR dog towards them, and then lead their dog from location A to location B and back. They were told that their AR dog is in training. As described in Section 4.2.2.1, the AR dog always tried to maintain the same distance (35 cm away) from the participant, but switched sides when walking back and forth to always stay on the side in between the participant and the confederate. Figure 4.4(b) depicts this interaction.

Participants were then guided back to the preparation booth for post-questionnaires, asking about their perception of the AR dog and the confederate. Once they completed the questionnaires, we brought them back in the interaction room, and they experienced another Phase 3–5 with a different confederate for a different awareness condition. Finally, participants were asked to complete post-questionnaires again and also questionnaires about their demographics and had a short interview session where the experimenter asked them about their experience and specifically their behavior with and without the AR dog.



(a) Play Session (Phase 2)



(b) Walking with Dog (Phase 5)

Figure 4.4: Experimental phases: Illustrations of (a) a person interacting with her AR dog in the play session in Phase 2 and (b) the person walking with her AR dog over the walkway in Phase 5.

4.3 Measures and Hypotheses

In this section, we present our measures and hypotheses based on the 2×2 mixed-factorial design described in the previous section.

4.3.1 Proxemics and Locomotion Behavior

In order to understand how the social presence of an AR dog changes participants' walking behavior compared to walking alone, and to understand how the conditions may additionally change their behavior, we computed the following measures from the logged head pose tracking information while participants were walking without the dog (*Phase 4*) and with the dog (*Phase 5*) from location A to B and vice versa on the walkway (see Figure 4.3). Figure 4.5 illustrates our behavioral measures described below.

- **Passing Distance** We measured the minimum clearance distance to the confederate when participants were passing by the confederate on the walkway. This distance is known to be an indicator of participants' personal space and social presence with other entities [14].
- **Walking Speed** We computed participants' average walking speed when moving from A to B and vice versa on the walkway. The AR dog's walking speed was capped at 0.5 m/s, hence walking faster or slower than this reference speed gives indications about participants' connection to their dog.
- **Head Rotations** To compute the amount of head rotations, we calculated the trajectory of the participant's gaze (forward vector) traveled on a unit sphere that surrounds the head (origin of the forward vector).
- **Trajectory Length** We computed the length of the path walked by participants from point A to B and back.
- **Observation Ratio** We computed the time participants looked at their AR dog and divided it by the total time when the collision between the AR dog and the confederate happened ± 5 s (*Phase 3*).

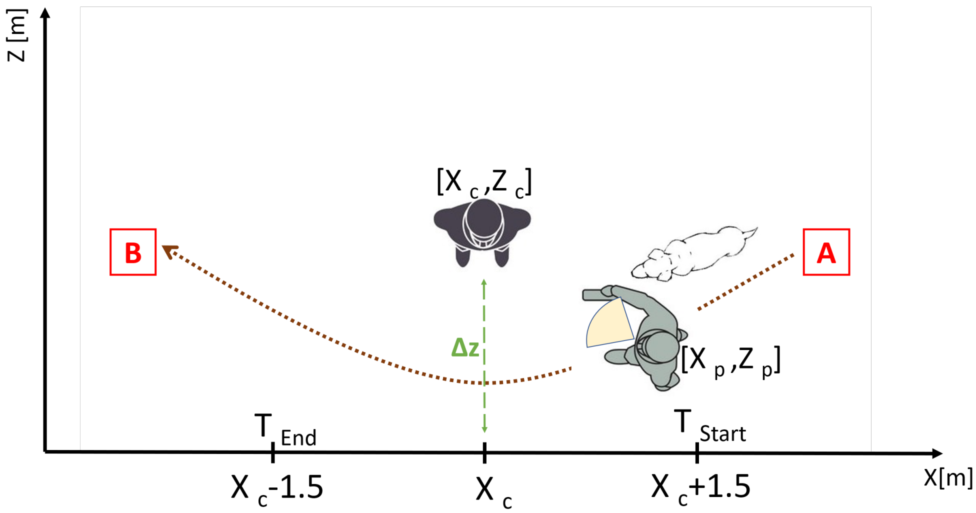


Figure 4.5: Illustration describing our analysis approach for our behavioral measures. To account for different participant profiles in initiation and/or stop of walking tasks we only used a range of walkway for our analysis centered ± 1.5 m around X_c (i.e., confederate's position on the X-Axis). Δz indicates passing distance, the dashed maroon line starting at T_{Start} and ending at T_{End} represents the trajectory length, division of trajectory length by T_{Start}-T_{End} results in walking speed, and the yellow sector indicates participants' viewing angle.

4.3.2 AR Animal Perception in a Shared Space

We utilized the following questionnaires to collect subjective responses from our participants. Due to the scarcity of questionnaires in VR/AR focused on animals, we opted to modify existing standard questionnaires and included an additional questionnaire focused on perceived physicality.

- **Co-Presence** To quantitatively measure the perceived sense of being together with an AR dog, we used Basdogan's Co-Presence questionnaire [28]. Since the questionnaire was not intended for animal types, we modified the questions for our purpose with an animal in mind, i.e., replacing humans with animals, and one out of the total eight questions was removed since no other task was defined for the participants except the interaction with and observation of their animal.

- **Godspeed** We chose the category "anthropomorphism" of the Godspeed questionnaire designed by Bartneck et al. [27]. However, we changed it to "animalism" by adjusting the questions that were associated with humans to animals instead.

- **Perceived Physicality** To assess the level of physicality, awareness, and intelligence our participants attributed with the AR dog, we devised a Perceived Physicality questionnaire shown in Table 4.1, which we modified from different sources [125, 144].

- **Affective Attraction** We used the Affective Attraction questionnaire designed by Herbst et al. [105] to assess participants' perception of the human confederates in the experiment, when they walked on the AR dog.

PH1	I felt as if my animal existed in the real (or physical) world.
PH2	I felt as if real/physical humans or objects could pass through my animal.
PH3	I felt my animal was aware of me.
PH4	I felt my animal was aware of its physical surroundings.
PH5	I felt as if my animal could walk through real/physical humans or objects.
PH6	I felt my animal had the intelligence to avoid collisions.

Table 4.1: Perceived Physicality questionnaire (with inverted statements for items PH2 and PH5).

4.3.3 Hypotheses

Our hypotheses were as follows:

H1 Participants will exhibit different proxemics and locomotion behavior when walking with the AR dog compared to walking alone.

H2 Participants will exhibit different proxemics and locomotion behavior:

I when the dog indicates awareness of the confederate compared to when it does not, regardless of the confederate's behavior/awareness.

II when the confederate indicates awareness of the dog compared to when it does not, regardless of the dog's behavior/awareness.

H3 Participants will experience a higher level of co-presence with the dog and perceive it as a more physical entity in the conditions where the dog is aware and reactive to the collision.

H4 Participants will score higher in the Animalism category of the Godspeed questionnaire in the conditions where the dog is aware and reactive to the collision.

H5 Participants will attribute lower levels of affect to the confederate through the affective attraction questionnaire:

I when the dog indicates awareness of the confederate, regardless of the confederate's behavior/awareness.

II when the confederate indicates awareness of the dog, regardless of the dog's behavior/awareness.

A summary of the measures used for each hypothesis and our expectations are shown in Table 4.2. Figure 4.6 represents the notation used for our conditions. Throughout the chapter, the letter **X** is used for the union of each two conditions (e.g., $C_{\text{U,A}} \cup C_{\text{U,U}} = C_{\text{U,X}}$) when making comparisons or analyzing the results for both the within-subjects variable (i.e., awareness level of the confederate) and the between-subjects variable (i.e., awareness level of the AR dog).

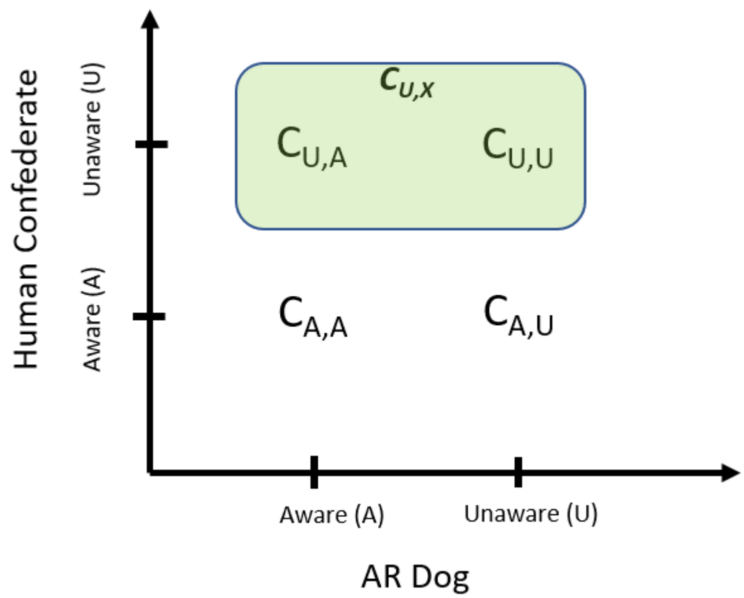


Figure 4.6: Summary of the experimental conditions and an example for the notations used for the analysis of our results.

4.4 Results

In this section, we present our subjective and behavioral results. As mentioned in Section 4.2.1, the results reported in this section are for 15 participants, 8 of which experienced the $\mathbf{C_{X,A}}$ conditions and 7 experienced the $\mathbf{C_{X,U}}$ conditions.

4.4.1 Proxemics and Locomotion Behavior

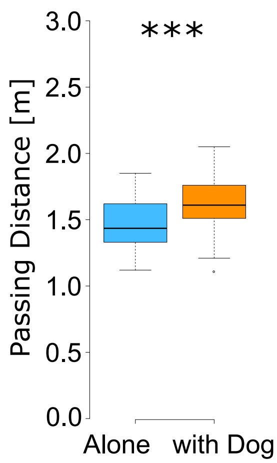
We analyzed the behavioral results with mixed ANOVAs and Tukey multiple comparisons with Bonferroni correction at the 5% significance level. We tested the normality with Shapiro-Wilk tests at the 5% level and confirmed it with QQ plots if in question. Degrees of freedom were

Hypothesis	Measure	Expected Results
H1	Passing Distance Walking Speed Head Rotations Trajectory Length Observation Ratio	Alone $\neq$ with Dog
H2-I	Passing Distance Walking Speed Head Rotations Trajectory Length Observation Ratio	$C_{X,A} \neq C_{X,U}$
H2-II	Passing Distance Walking Speed Head Rotations Trajectory Length Observation Ratio	$C_{A,X} \neq C_{U,X}$
H3	Co-Presence Perceived Physicality	$C_{X,A} > C_{X,U}$
H4	Animalism	$C_{X,A} > C_{X,U}$
H5-I	Affective Attraction	$C_{X,A} < C_{X,U}$
H5-II	Affective Attraction	$C_{A,X} < C_{U,X}$

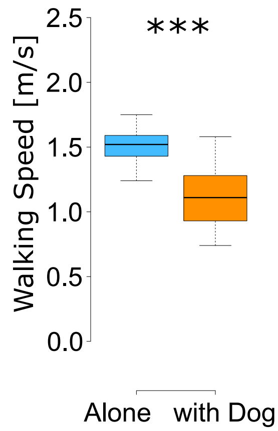
Table 4.2: Summary of the measures with respect to our hypotheses.

corrected using Greenhouse-Geisser estimates of sphericity in those cases when Mauchly's test indicated that the assumption of sphericity was violated. For significant effects, we report the corresponding effect size, commonly accepted in statistics literature [61, 242].

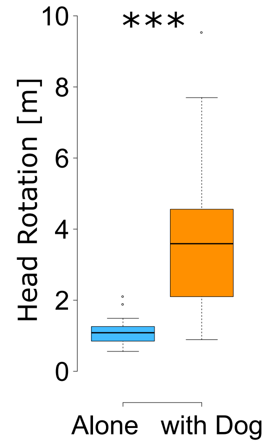
For the behavioral measures during walking, we analyzed both paths (i.e., from A to B and vice versa). The results reported are for path B to A unless we observed differences between the results of each path.



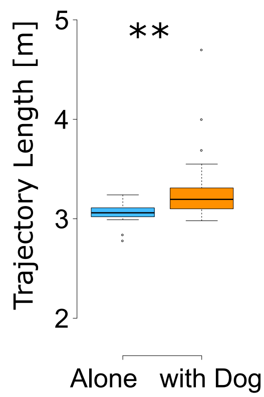
(a)



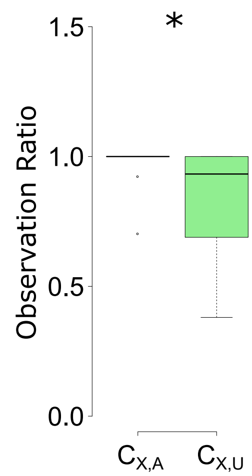
(b)



(c)



(d)



(e)

Figure 4.7: Proxemics and locomotion results: (a) Passing Distance, (b) Walking Speed, (c) Head Rotations, (d) Trajectory Length, and (e) Observation Ratio. Statistical significance: *** ($p<0.001$), ** ($p<0.01$), * ($p<0.05$).

4.4.1.1 Passing Distance

Figure 4.7(a) shows the passing distances when walking with and without the AR dog on the walkway in the different conditions. We found a significant difference between walking with an AR dog and walking alone in terms of the passing distance that participants maintained from the confederate standing on the walkway, $F(1, 58) = 23.52$, $\boldsymbol{p < 0.001}$, $\eta^2 = 0.19$. This indicates that the AR dog influenced participants' proxemics behavior in the sense that they allocated space for their AR dog. Moreover, this effect was independent of the experimental condition. We found overall similar behavior and no significant differences in passing distance between groups $\mathbf{C_{X,A}}$ **and** $\mathbf{C_{X,U}}$, $F(1, 28) = 0.0003$, $p = 0.98$, and groups $\mathbf{C_{A,X}}$ **and** $\mathbf{C_{U,X}}$, $F(1, 28) = 0.86$, $p = 0.36$. This implies that the social presence of the AR dog was the dominating effect, which dwarfed any effects related to the dog's awareness or the confederate's awareness.

4.4.1.2 Walking Speed

Figure 4.7(b) shows the walking speed when walking with or without the AR dog on the walkway in the different conditions. When comparing participants' walking speed alone and with the dog, we found a significant difference, $F(1, 58) = 70.17$, $\boldsymbol{p < 0.001}$, $\eta^2 = 0.23$ indicating that participants slowed down when walking with their AR dog. Similar to the effect on clearance distance, this effect on walking speed was largely independent of the condition. We found no significant differences in walking speed between groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $F(1, 28) = 0.73$, $p = 0.39$, and groups $\mathbf{C_{A,X}}$ and $\mathbf{C_{U,X}}$, $F(1, 28) = 0.079$, $p = 0.78$.

4.4.1.3 *Head Rotations*

Figure 4.7(c) shows the amount of head rotations performed by participants when walking with or without the AR dog on the walkway in the different conditions. We compared participants' head rotations alone and with the AR dog, and we found a significant difference, $F(1,58) = 45.38$, $\boldsymbol{p < 0.001}$, $\eta^2 = 0.6$ indicating that participants turned their head more with their AR dog, e.g., looking back and forth between the dog and the environment, than when they were alone. We found no significant differences in head rotations between groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $F(1,28) = 0.58$, $p = 0.45$, and groups $\mathbf{C_{A,X}}$ and $\mathbf{C_{U,X}}$, $F(1,28) = 1.09$, $p = 0.31$.

4.4.1.4 *Trajectory Length*

We compared the length of the path taken by participants and found a significant difference between instances of walking alone and walking with the dog, $F(1,58) = 11.96$, $\boldsymbol{p = 0.002}$, $\eta^2 = 0.23$ indicating that participants walked a longer path in each direction when walking with the dog. We found no significant differences in trajectory length between groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $F(1,28) = 2.08$, $p = 0.15$, and groups $\mathbf{C_{A,X}}$ and $\mathbf{C_{U,X}}$, $F(1,28) = 0.28$, $p = 0.6$.

4.4.1.5 *Observation Ratio*

When participants were observing their animal from the walkway in Phase 3, we computed the observation ratio of their AR dog and found significant differences for participants in groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $F(1,28) = 6.09$, $\boldsymbol{p = 0.02}$, $\eta^2 = 0.17$ indicating that participants dwelled longer on the aware dog that responded to the collision event. Figure 4.7 (e) illustrates this effect. We found no significant differences between participants in groups $\mathbf{C_{A,X}}$ and $\mathbf{C_{U,X}}$, $F(1,28) = 1.34$, $p = 0.26$.

4.4.2 AR Animal Perception in a Shared Space

The questionnaire responses for the within-subject factor of the AR dog's awareness were analyzed using Wilcoxon signed-rank tests at the 5% significance level. The results for the between-subject factor of the confederate's awareness were analyzed with Mann-Whitney U tests at the 5% significance level. We made exceptions to this procedure for those measures where the literature suggested parametric tests. Box plots in Figure 4.8 are in Tukey style with whiskers extended to cover the data points which are less than $1.5 \times$ interquartile range (IQR) distance from 1st/3rd quartile.

4.4.2.1 Co-Presence

We computed the scores for the Co-Presence questionnaire [28] in line with the literature as the mean ratings of the 7 items for each participant (Cronbach's $\alpha = 0.91$).

We found a significant main effect of the AR dog's awareness and behavior on Co-Presence between the participants in groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $U = 55.00$, ***p = 0.019,*** $r = 0.42$, shown in Figure 4.8(a), indicating that the dog's responsiveness to the collision increased the level of Co-Presence experienced.

4.4.2.2 Godspeed

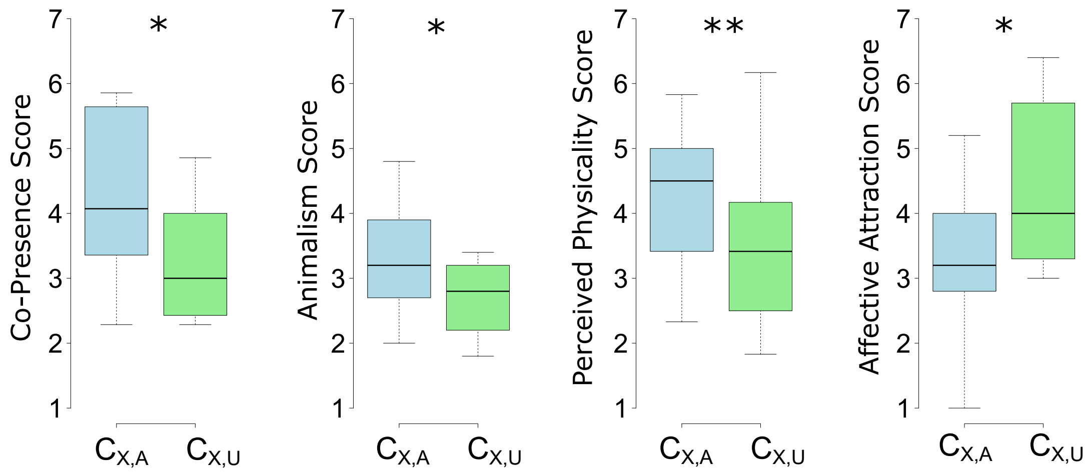
We calculated the scores for the Godspeed questionnaire [27] by computing the mean ratings for each category (Cronbach's $\alpha = 0.9$). We found a significant main effect for the AR dog's awareness and behavior in the *animalism* category between the participants in groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $F(1, 28) = 5.18$, ***p = 0.03***, $\eta^2 = 0.15$ shown in Figure 4.8(b), indicating a higher associated animalism in the conditions where the AR dog was aware of and responded to the collision with the confederate.

4.4.2.3 *Perceived Physicality*

To calculate the results for the Perceived Physicality questionnaire shown in Table 4.1, we computed the mean for all ratings for each participant (Cronbach's $\alpha = 0.71$). We found a significant main effect for the AR dog's awareness and behavior for Perceived Physicality between the participants in groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $U = 57.00$, $\boldsymbol{p = 0.02}$, $r = 0.41$, shown in Figure 4.8(c), indicating that the AR dog's reaction to the collision with the (physical) confederate increased their perception of the dog as a physical entity. Specifically, between groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, we found a significant effect for this factor for item PH4, $U = 48.00$, $\boldsymbol{p = 0.007}$, $r = 0.48$, and a trend for item PH3, $U = 67.5$, $p = 0.058$, $r = 0.33$, suggesting that the participants attributed the differences in reactive behavior of the AR dog to it being unaware of its physical surroundings and/or themselves.

4.4.2.4 *Affective Attraction*

To calculate the results for the Affective Attraction questionnaire [105], we computed the mean ratings for each participant (Cronbach's $\alpha = 0.8$). We found a significant main effect for the AR dog's awareness and behavior on ratings of affect between the participants in groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $U = 123.5$, $\boldsymbol{p = 0.043}$, $r = 0.39$, shown in Figure 4.8(d), indicating that lower affect was perceived when the AR dog was aware of the collision with the confederate's foot and reacted to it.



(a) (b) (c) (d)

Figure 4.8: AR animal and confederate perception results: (a) Co-Presence, (b) Godspeed Animalism category, (c) Perceived Physicality, and (d) Affective Attraction. Statistical significance: ** (p<0.01), * (p<0.05).

4.4.3 Qualitative Feedback

We logged whether or not participants addressed their dog by its name during the play session (*Phase 2*) and the different ways they called their dogs towards themselves on the walkway during *Phase 5*. Table 4.3 shows the personalized names participants gave their AR dogs and their choices in terms of the dog's appearance.

In *Phase 2*, 2 out of 15 participants called their dogs with their name more than ten times, 4 used their name a few times, and 10 never used their name. 7 participants used their dogs' name in *Phase 5* while the remaining 8 used more general terms such as *"Come here!"* Also, amongst our participants, we observed that 3 of them regularly used encouraging words such as *"Good Boy!"* when interacting with their dog during this phase. We did not find any significant correlations between participants pet/dog ownership and how they addressed their AR dog.

AR dog (a)	AR dog (b)	AR dog (c)	AR dog (d)
Beans	Patrick	Max	Apollo
Benzy	Samson	Rockey	Tom
Bolt One	Simba	Rover	
Icey	Smoke		
Marlo			
Rui			

Table 4.3: Different dog names chosen by participants based on the designs in Figure 4.1.

At the end of the experiment, we asked our participants in a short interview session about their thought process during the walking tasks when walking alone and when walking with their AR dog. For the walking alone sessions, the majority of the participants mentioned that they thought of leaving enough space so they would not hit the participant. Interestingly their strategies were more diverse when walking with the dog as it was a more novel interaction for them. When asked about their chosen walking path with the dog, their rationale were either, (a) that they gave enough space so it wouldn't bump into things, or (b) they became aware of the fact that maybe they should allocate more space for the dog in the future walks and adjust their future behavior even more than they already had after one walk with the dog. There were a few exceptions, such as one participant that mentioned that she did not need to make any adjustments as she had already allocated enough space. Surprisingly one participant noted that she started thinking about her path choices while she was walking alone the first time around and mentioned, *"I thought that maybe I should give more space as I'm going to walk with the dog next"*.

When asked about whether or not they felt they have to look back at the dog or not, for those who looked back a lot, the main reason was *"to make sure the dog is following"* or *"is not left behind"*. The topic of trust was also raised for three of our participants as one mentioned that the reason she didn't look back was due to the dog's interactive behavior even when she was just observing it which resulted in a higher sense of trust. Completely opposite to this comment, another person noted that he looked back more often due to his lack of trust as the dog was unaware and walked over. Another participant mentioned that she didn't know if she should go back and get it if it stopped which resulted in multiple checks on her dog. Another person noted that his reason for looking back was to check for further interactions between the dog and the confederate.

4.5 Discussion

In the experiment described here, we observed that an AR dog that exhibits *awareness* (i.e., is aware of another person during a collision event and reacts appropriately) impacted participants' perceptions of both the AR dog and the other person. We also observed that, regardless of the condition, whether or not the AR dog was present significantly changed participants' proxemics behaviors during a locomotion task in a shared space. In this section we discuss each of these findings in more detail.

4.5.1 Effect of an AR Dog on Proxemics and Locomotion Behavior

The main finding from our analysis of the behavioral measures collected from participants is that the presence of the AR dog significantly changed how participants moved and oriented themselves compared to a baseline condition when they were alone. This effect was observed even though participants were being observed by another person, regardless of whether or not that other person showed any awareness of the AR dog. This suggests that the impact of the AR dog being present was strong enough that participants did not alter or restrain their behavior in front of another person, in some cases even still verbally encouraging the dog to move.

Participants' passing distance, walking speed, head rotations, and trajectory length showed significant differences when walking with the AR dog as compared to walking alone, supporting our hypothesis **H1**. This indicates that the interaction with the AR dog, regardless of the dog's level of awareness of others, was still strong enough to invoke a significant change in behavior. Participants allocated additional space for the dog when walking with it, apparent both through increases in their passing distances and trajectory lengths and in their qualitative responses presented in Section 4.4.3. Although we did not measure for factors such as attachment or sense of ownership that might result in more attentive behavior, we found it interesting that participants decreased their walking speed and frequently rotated their heads to visually check on their AR dog—possibly an indication of indirect measures of attention as has been explored by other researchers who used head orientation and gaze as a proxy for focus of attention in different contexts [168, 256]. It is important to note that these behaviors, sometimes even more pronounced, seemed to persist, as mentioned in Section 4.4.3, specifically with respect to passing distances, despite the possible expectation that the reduced novelty of the interaction might diminish the effect on participants' behavior.

We found a significant difference in the observation ratio of the AR dog, depending on whether or not the dog displayed awareness of the collision event. This indicates that the observation of the dog's awareness during the collision contributed to a higher level of attentiveness from the participants, supporting part of our hypothesis **H2-I**. We did not find significant differences for the remaining measures with respect to the AR dog's awareness, and also found no significant differences with respect to the awareness and wearing of AR glasses of the confederate, to support the remaining aspects of our hypotheses **H2-I** and **H2-II**. We do acknowledge that the lack of significance here is not indicative of lack of importance of the awareness levels of the confederate and the AR dog and a larger sample size will be required to understand how awareness of each entity can impact proxemics and locomotion behavior. The short duration of the interaction with the dog may also have had an effect on the level of attachment and ownership experienced by participants, resulting in less significant behavioral changes. This is in line with some of the findings of Weiss et al., comparing child and adult behaviors during a free exploration session with a robotic dog in which they concluded that a short interaction interval may not be sufficient to form an emotional attachment [263]. Also, a longer or more malicious interaction with the confederate, e.g., multiple or repeated collision events, could have resulted in more significant changes in participants' behavior.

4.5.2 Effect of an AR Dog's Awareness on Participant Perception

The overarching finding from our subjective measures emphasizes the impactfulness of the AR dog's awareness and behavioral realism, as well as the role that other people can play in a AR space—even if they may not appear to be aware of or experiencing any of the AR aspects of that shared space.

In the results from the Co-Presence questionnaire [28], we found that interaction with and observation of the *aware* AR dog (which reacted to the collision with the other person by falling over and whining), increased the sense of co-presence experienced by the participants, supporting our hypothesis **H3**. This was observed despite the fact that the dog's awareness of the other person was demonstrated through only a very brief interaction (a few seconds) which the participant only passively observed. This finding supports the notion that virtual entities can affect human perception and behavior [229], and is in line with previous research indicating that behaviors of virtual humans which suggest that they can *affect* or *be affected by* the physical world invoke a higher sense of co-presence or social presence (i.e., "awareness of the co-presence of another being" [35]) for users interacting with them. For example, work by Kim et al. in which a virtual human was correctly occluded when sitting behind a table [125] or was aware of a physical blowing fan [126], or Lee et al.'s findings on the impact of a virtual human's ability to move physical objects [147]. We also observed that our participants associated a higher degree of Animalism to the aware and responsive AR dog compared to the unaware one, supporting our hypothesis **H4**. This is interesting, in part, due to the fact that having a degree of awareness is described as one of the qualities of a sentient being [47, 48], and the Animalism questionnaire (i.e., an adjusted category of the Godspeed questionnaire [27]) includes questions that aim for measuring sentience.

Research has shown that people's behavior in a virtual environment can be similar to real life when one experiences the "sense of being there" in the virtual environment and perceives the illusion of "that what is apparently happening is really happening" [235]; likewise, virtual experiences can impact one's perception and behavior in the real world. In line with this idea, we observed that participants associated a lower affect score to the confederate who walked over the *aware* AR dog, regardless of the awareness level of that confederate, supporting our hypothesis **H5-I**. This suggests that the dog's awareness, which emphasized the unpleasantness of the event (i.e., by falling over and whining), impacted how participants perceived the other person. However, we did not find significant differences in this regard between the confederate who showed awareness of the AR dog and the one who did not, to support our hypothesis **H5-II**. We think that the short duration of the confederate-AR dog interaction might have been a contributing factor for this lack of significance. Also, a longer interaction between the AR dog and the participant (i.e., the AR dog's owner) could help establish a sense of attachment or ownership, which has been shown to impact owners' emotions and behaviors with respect to their real pets [278]. This heightened sense of ownership may be required to understand how other people's interactions with one's *own* AR animal affect its perception.

We found significant differences in responses to the Perceived Physicality questionnaire supporting our hypothesis **H3**, indicating that an AR dog that is aware of, and shows a realistic response to, the collision with the other person is perceived as more physical, more aware of its environment (significance in PH4 data), and seems more aware of its owner (trend in PH3 data). These findings are interesting because even though the only behavioral difference between the *aware* and *unaware* AR dog was during the brief collision event, i.e., the dog was otherwise programmed to be equally attentive to the participant, that single event, which was initiated by another person, may have affected not only the dog's perceived awareness of the environment but to some degree the perceived awareness of the participant as well.

These results support the idea that the introduction of another person to an AR experience or interaction can reinforce or redirect one's perception of that experience, introducing new future research questions. For example, in the context of human-AR companion animal relationships, a high level of experienced co-presence due to an AR animal's realistic (aware) behavior, e.g., when getting walked on in a busy street, might actually have potentially negative or distressing effects on the owner. This suggests that in certain contexts, a higher degree of co-presence, physicality, etc. might not necessarily be the best technological realization for such AR companions.

4.6 Conclusion

In this chapter, we presented a human-subject study to investigate the impacts of the presence of an AR dog on participants' proxemics and locomotion behavior as well as their perception of the dog in a shared environment with other people. The study comprised different phases in which participants personalized their AR dog, interacted with it, witnessed a collision event between the AR dog and another person, and then performed a locomotion task both without, and finally with, their dog. We varied the AR dog's awareness of another person and the other person's awareness of the dog, while walking over and colliding with it. We found that walking with the AR dog invoked a different walking behavior compared to walking alone when there was a by-stander (e.g., the confederate in our study), and the dog's awareness of and reactive behavior with other people positively impacted the participants' level of perceived Co-Presence, Perceived Physicality, and Animalism of the AR dog.

In the future, we plan to explore different aspects of interactions between real humans and virtual animals, beyond the AR dog used in this study. The influence of a longer duration interactions and a more task oriented AR animal should be considered and researched with respect to human perception and behavior. As AR research converges with other technology fields, such as artificial intelligence (AI) and the Internet of Things (IoT), AR animals could become increasingly interactive with and responsive to the surrounding physical environment. We will also look for opportunities to understand how such physically interactive behavior of AR animals can influence the user's perception and extend the ability to control the environment.

CHAPTER 5: VIRTUAL DOGS AS SOCIAL SUPPORT FIGURES

This chapter presents a human-subjects user study exploring two aspects of the Human Effects category presented in Chapter 1, namely the Physical and Mental Effects, where the influences of interactions with virtual dogs as support figures are evaluated. Inspired by previous HDI and social support literature, we compare the influence of virtual dogs as support figures and compare it to a virtual human and a no support figure condition, only focusing on the Visual Representation aspect of the five Research Considerations identified in our systematic literature review [189].

The thesis statement supported by this chapter are as follows:

- **[TS1] Entity-Self:** The presence of a virtual dog with dog-like behaviors can induce subjective changes within *real human interactants*, including:
  - **[TS1.2]** Increased levels of perceived support in front of the virtual dog

This chapter largely incorporates a manuscript that is submitted for publication at the time of this dissertation publication: "The Advantages of Virtual Dogs Over Virtual People: Using Augmented Reality to Provide Social Support in Stressful Situations," authored by Nahal Norouzi, Kangsoo Kim, Gerd Bruder, Jeremy Bailenson, Pamela Wisniewski, and Greg Welch.

5.1 Overview

While real humans and animals [9, 46, 60, 88] have been identified as important sources of social support, it is less clear whether virtual humans and animals might afford the same benefits. Understanding the potential of virtual counterparts becomes more important, specially when no real alternatives (i.e., no support figure) are available. A few studies in virtual reality (VR) have looked at the potential of virtual humans in the provision of support [86, 112, 135]; yet, to our knowledge, no studies have compared the effectiveness of both virtual humans and virtual animals as social support figures in general, and more specifically, through the AR paradigm that offers the 3D in-situ integration of virtual support figures in the user's physical environment.

As such, we pose the following high-level research questions aimed to assess the effectiveness of a virtual human and a virtual dog in the absence of real support in the context of outcomes commonly associated with reception of social support, such as reduced stress, and better performance.

- **RQ1**: *Can virtual dogs in AR provide effective social support?*
- **RQ2**: *Can virtual dogs provide better social support than virtual humans in AR?*

The findings of this chapter support **TS1**, as our participants evaluated the virtual dog support figure more positively than the virtual human and no support figure conditions and showed a stronger preference towards this condition than the virtual human support figure. A qualitative analysis of our participants' post-study interview data is aligned with these findings as it revealed that a virtual support figures' non-judgemental nature might be an important characteristic for its effectiveness, which corresponds to previous findings on real support figures [9, 88, 206]. This characteristic can affect how comfortable a person is with their support figure as in our study, several participants attributed their increased comfort with the virtual dog due to its lack of judgment.

5.2 Experiment

In this section, we describe the experiment we conducted to study the influence of the presence and absence of different virtual support figures on participants' performance as well as subjective and physiological stress.

5.2.1 Participants

We recruited 33 university-affiliated individuals (8 female, 25 male, age: $M = 24.45$, $SD = 4.36$) to participate in our study. Our experimental protocol was approved by the institutional review board of our university, and all participants were compensated directly after the study. All participants indicated that they had no phobia of dogs or generally disliked dogs before taking part in the study. Using a 7-point Likert scale (1 = no familiarity/novice, 7 = high familiarity/expert), we asked our participants to rate their familiarity and expertise with computers ($M = 5.82$), virtual reality ($M = 5.03$), augmented reality ($M = 4.76$), virtual humans/avatars/agents ($M = 4.57$), and virtual animals ($M = 3.48$). Eleven participants (33%) were pet owners and 15 participants indicated that they had played games, which included animals/pets in companion and enemy roles. We also assessed our participants' attitudes towards pets using the Pet Attitude Scale questionnaire [248] from the scale of 1 (low favorable attitude towards pets) to 7 (high favorable attitude towards pets) with an overall reasonably favorable attitude towards pets ($M = 5.43$).

5.2.2 Material

In this section, we present our implementation of the virtual support figures and the design choices for our experimental task and space.

5.2.2.1 Support Figure Implementation

In our experiment, a virtual dog and a female virtual human were chosen as the virtual support figures. The virtual dog was a purchased 3D character from the Unity Asset Store[1], which is

[1] https://assetstore.unity.com/packages/3d/characters/animals/dog-beagle-70832

rigged and animated. The normal vectors in the original model were slightly adjusted to smooth out some of the edges on the virtual dog. The virtual human 3D character was modeled, rigged, and animated using Blender and AutoDesk Maya. The Unity Engine version 2018.3.14f1 was used to program the behavior of the two virtual support figures and the general control of the experiment, such as information logging, timing, and start/stop prompts on an optical see-through head-mounted display (HMD), Microsoft HoloLens 1 (frame rate: 60 Hz, field of view: $30\,^{\circ} \times 17\,^{\circ}$, and resolution: 1268×720 per eye [17, 174]). The baseline and random expressions of the virtual support figures were set to be positive and calming. This choice was inspired by findings from work by Christendeld et. al. [60] where real humans with positive expressions were deemed more supportive than those with neutral expressions. We applied this finding to the behaviors of both virtual support figures for a more equivalent design, while aiming for behaviors that are natural for each entity. The baseline expressions of the virtual support figures were set to be slightly smiling.

Additionally, throughout the experiment, every 12 seconds, the virtual human would either randomly increase its smile (i.e., eyebrows and lips gradually moving upward; the value for the corresponding blendshape increased from 30 to 60) or nod, and the virtual dog would randomly increase its smile (i.e., lips gradually moving upward and eyes moving downward; the value for the corresponding blendshape increased from 40 to 80) or tilt its head. The change in blendshape values were chosen based on pilot testing to ensure that the resulting facial expressions are not exaggerated. We chose these behaviors for the virtual dog as they can convey positivity. For instance, the perceived smiling behavior of dogs [262] is exhibited by changes in the shape of their mouth and eyes indicating their relaxed state [18]. Similarly, a head tilt can indicate a dog's curiosity or interest, its attempt to enhance its visual perspective or sound localization, and has been shown to enhances humans' perceptions of dog's cuteness [10, 63, 92, 156]. However, these behaviors may have been viewed differently than we intended which we discuss in Section 5.4.3.

Overall, the behaviors of our virtual support figures are less interactive than behaviors such as a virtual human clapping or a virtual dog playing. This choice was inspired by previous social support literature that utilized setups where, similar to ours, the support figures were present during the study tasks [60, 88] to attenuate any potential distraction brought about by the support figures while maintaining their positivity. To ensure that participants can view both support figures in their field of view while looking straight ahead (i.e., similar physical demand), we decided to place the virtual dog higher on several books and a chair. This choice allowed us to maintain the size of the virtual dog similar to a real dog of its breed (i.e., a beagle). This choice introduces the potential of the virtual dog being perceived as anthropomorphic, which we further discuss in Section 5.4.3. The final state of these expressions and their behaviors are shown in Figure 5.1. A graphics workstation with the specifications of Intel Xeon 2.4 GHz processors comprising 16 cores, 32 GB of main memory and two Nvidia Geforce GTX 980 Ti graphics cards was used for controlling the stimuli presented to the participants. An additional laptop was used by the participants to answer the questionnaires.

5.2.2.2 Experimental Task and Setup

To create a stressful environment for our participants, we incorporated experimental settings similar to the previous social support studies presented in Section 2.1.1, e.g., the Trier Social Stress Test [133]. *Serial Subtraction by Seven* was chosen as the stressful task, which has been shown to induce stress and increase heart rate [216]. Three numbers, 2178, 4895, and 5487, were randomly chosen as starting numbers for the serial subtraction task. The experimenter wore a lab coat before the start of the first condition and told the participants that she would be judging their performance. Also, as illustrated in Figure 5.2, two cameras, pointed at the participants, were placed in the room. A microphone was placed in front of them and slightly to their right. The experimenter would turn these devices on in front of the participants before the start of the first session and sit at a 152 cm by 76 cm desk across from them and slightly to their right. The experimenter kept a neutral expression

(a) Baseline (b) Tilt Head (c) Smile

(d) Baseline (e) Nod Head (f) Smile

Figure 5.1: Screenshots showing the (left column) baseline expressions and (right columns) behaviors of the virtual support (top) dog and (bottom) human, which were defined to be slightly positive/supportive.

throughout the task and looked at the participants while pretending to type on a laptop in front of her. Participants wore a TICKR FIT heart rate monitor on the forearm of their non-dominant hand throughout the experiment, and their heart rate was collected through the Wahoo app, which was synchronized with this tracker[2].

[2] https://www.wahoofitness.com/devices/heart-rate-monitors/tickr-fit-optical-heart-rate-monitor

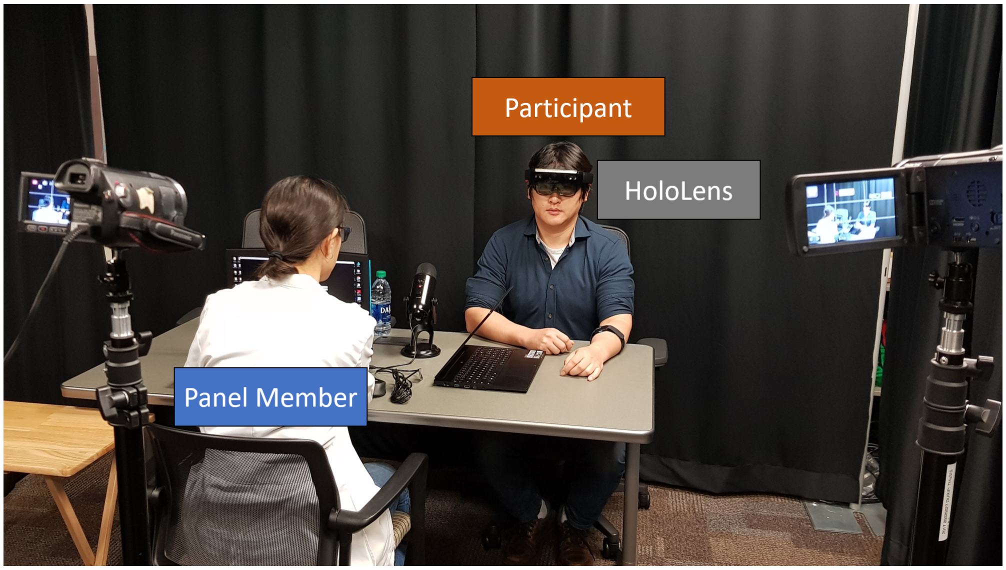


Figure 5.2: Annotated photo of our physical setup, showing a participant in the experiment as well as the experimenter in the lab coat, judging the performance of the participant.

5.2.3 Method

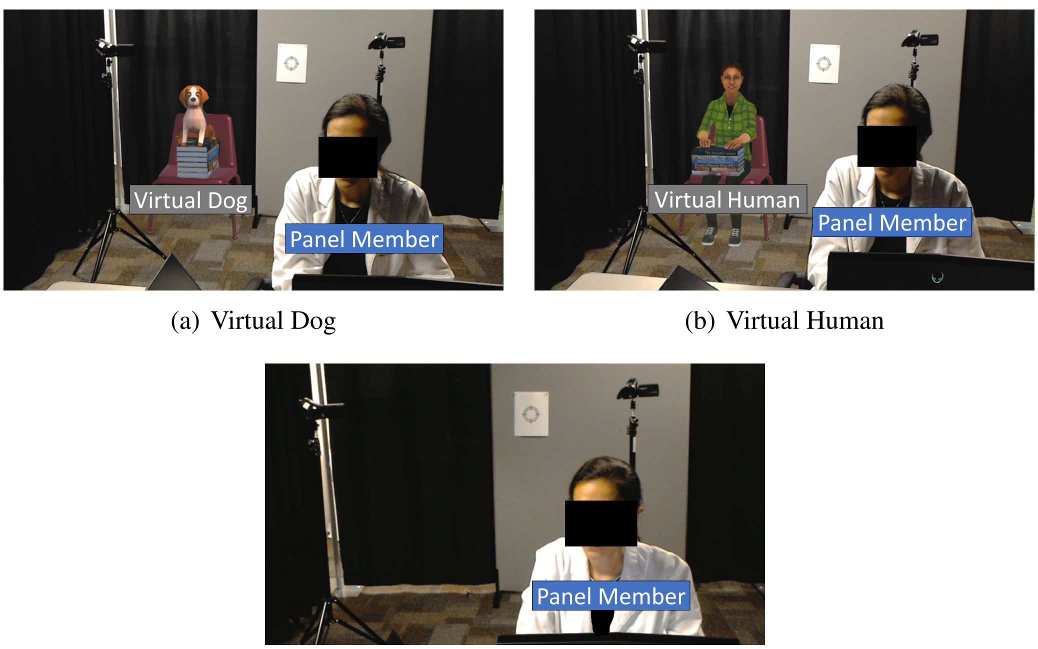
We chose a within-subjects design with one factor (three levels) for our study where the conditions were (see Figure 5.3):

- **Virtual Dog Support Figure (Dog)**
- **Virtual Human Support Figure (Human)**
- **No Support Figure (None)**

The choices for our independent variables were influenced by the goal to replicate virtual counterparts of the human and dog support figures tested in previous social support studies [9, 206] with the exception that in our study the virtual support figures are strangers to the participants. The three conditions and the three numbers chosen for the experimental task were randomized to account for order effects and to ensure that different conditions are tested with the different start numbers in the mental arithmetic task. In our experiment, the effects of the panel member was held constant as she was present in all three conditions.

5.2.3.1 *Procedure*

Participants were accompanied to the lab area and were given the consent form. After giving their informed consent, they were guided to the experimental space shown in Figure 5.2. They were asked to answer questionnaires to assess their familiarity with technology. Participants were given instructions on the mental arithmetic task, which consisted of serial subtractions by seven from



(a) Virtual Dog

(b) Virtual Human

(c) No Support

Figure 5.3: Participants' view while completing a stressful mental arithmetic task in the presence of an experimenter (panel member) in a lab coat as well as a *support figure*: (a) virtual dog, (b) virtual human, or (c) no support figure.

one of the three 4-digit numbers (2178, 4895, and 5487), which were randomly chosen for each condition. They were asked to vocalize the numbers, speak loudly, not to close their eyes during the task, and to keep their attention forward to keep both the experimenter and the area where the virtual support figures would be placed in their field of view. Participants were asked to confirm that they can see the all of the virtual dog sitting on the books and the virtual human from the torso up while they were looking straight ahead. Participants were told that their performance will be judged by the experimenter and to keep both speed (i.e., doing more subtractions during the three-minute task) and accuracy of subtractions as measures for their performance. The experimenter placed a heart rate monitor on the participant's forearm and asked them to keep their arm still either on the armrest or the desk and not move the chair during the experimental sessions.

Before experiencing the actual study conditions, participants spent five consecutive 1-minute sessions getting familiar with the idea of the task by doing serial subtractions by three from a set of randomly ordered pre-chosen 4-digit numbers (1351, 2266, 3689, 5773, and 6512). The experimenter notified participants of the end of each minute during the practice session and left the room. After the familiarization phase, participants spent 5 minutes alone watching a relaxing video[3].

Afterward, the experimenter came back to the room, started the recording on the two cameras and the microphone, and the participants wore the Microsoft HoloLens 1. After ensuring that participants were ready, the experimenter started with one of the randomly assigned conditions—either the virtual dog, the virtual human, or no support figure. Then, participants answered a few questions on the laptop regarding stress, anxiety, and perceived difficulty. Afterward, participants performed the serial subtractions task for three minutes per condition as described in Section 5.2.2.2. If participants forgot a number and could not continue, the experimenter would repeat their last response. After the end of each condition, participants first answered a few questions about stress,

[3]https://www.youtube.com/watch?v=r3fE6FQT82s

anxiety, and perceived difficulty with the HoloLens on. Then, they took the HoloLens off and answered several questionnaires assessing their attitude towards the support figure and their perceived stress. This procedure was repeated for all three conditions. After the last condition, participants took part in a short interview. Then, the experiment ended with providing monetary compensation to the participants.

5.2.3.2 Hypotheses

Our hypotheses were based on the findings from previous social support studies [9, 26, 60, 88, 206], suggesting that pets or entities that do not have an evaluative/judgmental nature but exhibit supportive behavior can decrease heart rate, improve performance due to not inducing feelings of evaluation apprehension, and positively influence subjective evaluations, such as perceived stress levels or task difficulty. Our hypotheses for this study are as follows:

H1 Participants will exhibit better performance in terms of a higher (a) number of subtractions and (b) accuracy rate in front of the virtual dog compared to either being alone or in front of the virtual human.

H2 Participants' heart rates will increase either without the support figure or with the virtual human, but they will remain more stable in the presence of the virtual dog support figure.

H3 Participants will (a) experience higher levels of perceived support, (b) have a higher preference, and (c) deem the task as less difficult in front of the virtual dog compared to either being alone or in front of the virtual human.

H4 Participants will assess their (a) stress and (b) anxiety levels as lower in front of the virtual dog compared to either being alone or in front of the virtual human.

5.2.3.3 Measures

In this section, we describe the objective and subjective measures used to test our hypotheses.

5.2.3.3.1 Objective

To assess the influence of the type and presence of different support figures, we collected participants' heart rate data (bpm) and assessed their task performance based on the number of subtractions and accuracy rate during the mental subtractions task.

- **Performance (H1):** To assess participants performance, we utilized two approaches adapted from related measures introduced by Allen et al. [9], which are in line with our serial subtraction task instructions given to our participants (see Section 5.2.3.1). Although the two approaches are related, we decided to utilize both as previous research suggested that they do not necessarily follow the same pattern [9].

  1. We used *number of subtractions*, as the total subtractions completed within the three-minute duration of the task per the instruction of keeping speed (i.e., doing more subtractions) as a performance factor.
  2. We used *accuracy rate*, as the amount of correct subtractions divided by the total number of subtractions during the three-minute task per the instruction of keeping accuracy of subtractions as a performance factor.

- **Mean Heart Rate (H2):** From the physiological sensor data, we computed the *mean heart rate* of the last 3 minutes of the relaxing period and the 3-minute task time for each of the conditions (following a similar approach by Fontana et al. [88]).

5.2.3.3.2 *Subjective*

To assess our participants' subjective perception of the support figures and the task at hand we utilized the following questionnaires.

- **Support Figure Evaluation (H3):** We made adjustments to a validated questionnaires by Gee et al. [90] for assessing participants' evaluation of the support figures (a real dog in their experiment) in the different conditions, which consists of multiple questions using a 7-point Likert scale (1 = Strongly disagree, 7 = Strongly agree). The adjusted questionnaire focuses on factors, such as perceived comfort and likeability of support figure which can influence the quality of received support [113, 120, 247]. Table 5.1 shows these questions.

- **Perceived Difficulty (H3):** To assess how difficult the task is going to be or has been for our participants, we presented them with two 7-point Likert scale (1 = Strongly disagree, 7 = Strongly agree) statements and asked for their rating exactly before and after each condition. The statements were: (a) "I think the task will be challenging.", and (b) "I think the task was challenging."

- **Preference (H3):** After participants had experienced all three conditions, we asked them to choose their most and least preferred conditions based on how comfortable they felt.

ID	Question
SFE1	I was completely comfortable with the virtual animal/virtual human/being alone.
SFE2	I really liked the virtual animal/virtual human/being alone.
SFE3 (-)	The virtual animal/virtual human/being alone made me uncomfortable.
SFE4	I felt more relaxed when the virtual animal/virtual human/nobody was present.

Table 5.1: Perceived Support questionnaire. Answers are reversed for the negative item (marked with "-").

- **Perceived Stress and Anxiety (H4):** To assess participants perception of their stress and anxiety we utilized two single-item questions.

  We asked our participants to answer two questions about their stress and anxiety levels right before and right after each condition using a 7-point Likert scale. These questions were: (a) "How stressed are you at this moment?" (1 = Not stressed at all, 7 = Very stressed), (b) "How anxious are you at this moment?" (1 = Not anxious at all, 7 = Very anxious).

- **Post-Study Interview:** Participants took part in an interview session after completing all three conditions and questionnaires. The purpose of the interview was to better understand their experience with the different support figures. Specifically, they were asked to describe their experience in terms of their stress levels, performance, and distraction with regards to the different support figures. Stress and performance were chosen as they are generally representative of our subjective and objective measures, potentially leading to a better understanding of their performance and subjective response to our questionnaires. Distraction was chosen as it could provide us with insights with regards to the design of virtual support figures in the future.

5.3 Results

We followed a mixed-methods data analysis approach for our quantitative and qualitative data. Overall, three participants (2 males, 1 female) were removed from our mixed-methods analysis due to issues with recordings of heart rate data or questionnaire data in one of their sessions. We used repeated measures ANOVAs for the analysis of both of our subjective and objective quantitative results in line with the ongoing discussion in the field of psychology indicating that parametric statistics can be a valid and informative method for the analysis of combined experimental questionnaire scales [134, 138], with a few exceptions relying on a non-parametric Friedman test when

Shapiro–Wilk test and Q-Q plots rejected the normality of the data. In cases were sphericity was not assumed using Mauchly's test, Greenhouse-Geisser corrections were applied. We used paired samples t-tests and Wilcoxon signed rank tests for the pairwise comparisons. Table 5.3 summarizes all of our significant and non-significant findings.

To analyze our post-study interview questions, we utilized a thematic analysis [44] approach to better understand our participants' perceptions and preferences in relation to the different support figures. The qualitative analysis is the result of the collaborative effort of the first and last two co-authors. Following the phases of thematic analysis, after the data familiarization phase, we created codes for the various ideas presented in the data and through an iterative process these codes were conceptually grouped together to represent themes. A priori hypotheses were not used during the thematic analysis process allowing for the themes to emerge in an inductive way. Table 5.2 represents our themes and codes. We identified three major themes, which include participants' perception of comfort and support figure judgement, interactivity, and influence on concentration. In our results, we present illustrative quotes to further unpack these themes.

Themes	Code: Definition
Virtual dogs are perceived as more supportive than virtual humans	Comfort: virtual support figure's influence on increasing or decreasing comfort Stress: virtual support figure's influence on reducing or inducing stress Judgement: virtual support figure's influence on inducing or taking away perceptions of being judged
Virtual people are perceived as more interactive than virtual dogs	Smiling/Nodding: virtual support figure's expressions being explicitly discussed. Interactivity: virtual support figure's expressions being noticed in a general way. Stagnant: virtual support figure's expression being missed or forgotten.
Virtual humans may be perceived as slightly more distracting than virtual dogs	Distraction: virtual support figure's influence on distraction. Focal/Focus Point: virtual support figure's influence on concentration. Empty Space: virtual support figure's influence in relation to no support figure.

Table 5.2: Thematic Analysis Codebook.

Measures	Main Effect	Pair-Wise Comparison
Performance: # of Subtractions	$\chi^2 = 5.33$, $p = 0.07$	—
Performance: Accuracy Rate	$\chi^2 = 2.23$, $p = 0.32$	—
Δ Heart Rate	$F(2, 18.65) = 2.08$, $p = 0.13$, $\eta_p^2 = 0.07$	—
Support Figure Evaluation	$F(1.55, 13.73) = 4.84$, $\boldsymbol{p = 0.019}$, $\eta_p^2 = 0.14$	Dog vs. None: $t(29) = -2.58$, $\boldsymbol{p = 0.015}$, $d = 0.55$ Dog vs. Human: $t(29) = -3.41$, $\boldsymbol{p = 0.002}$, $d = 0.84$
Preference	$\chi^2 = 6.67$, $\boldsymbol{p = 0.04}$	Dog vs. None: $W = 163.50$, $Z = -1.54$, $p = 0.12$, $r = 0.28$ Dog vs. Human: $W = 115.50$, $Z = -2.49$, $\boldsymbol{p = 0.013}$, $r = 0.45$
Perceived Difficulty (pre-post)	—	None: $W = 100.00$, $Z = -0.89$, $p = 0.37$, $r = 0.16$ Human: $W = 26.00$, $Z = -2.05$, $\boldsymbol{p = 0.040}$, $r = 0.37$ Dog: $W = 110.00$, $Z = -0.20$, $p = 0.84$, $r = 0.03$
Perceived Anxiety (pre-post)	—	None: $W = 63.00$, $Z = -2.44$, $\boldsymbol{p = 0.02}$, $r = 0.44$ Human: $W = 25.00$, $Z = -2.69$, $\boldsymbol{p = 0.02}$, $r = 0.49$ Dog: $W = 48.00$, $Z = -1.72$, p = 0.06, $r = 0.31$
Perceived Stress (pre-post)	—	None: $W = 5.00$, $Z = -3.91$, $\boldsymbol{p < 0.001}$, $r = 0.71$ Human: $W = 12$, $Z = -3.67$, $\boldsymbol{p < 0.001}$, $r = 0.67$ Dog: $W = 37.50$, $Z = -2.76$, $\boldsymbol{p = 0.006}$, $r = 0.50$

Table 5.3: Summary of significant and non-significant results.

5.3.1 Objective Measures

Table 5.4 summarizes the means/medians and standard deviations of our objective results for the three conditions. Medians were reported for measures with data deviating from normality.

Measures	Timing	None	Human	Dog
# of Subtractions ($_\sim$)	During	38.00 (16.53)	37.50 (16.08)	38.50 (14.73)
Accuracy Rate ($_\sim$)	During	91.67 (10.40)	94.10 (9.28)	93.42 (9.98)
Heart Rate	Pre	72.06 (9.46)	72.56 (9.65)	73.76 (10.26)
	During	76.18 (8.82)	75.36 (8.93)	76.45 (8.94)

Table 5.4: Summary of the means/medians (standard deviations) for the objective measures for the three conditions. Medians were reported for measures with data deviating from normality and are marked with "($_\sim$)" next to appropriate measures. The term *during* indicates measures collected while the task was happening, while the terms *pre* and *post* are indicative of measures collected before and after the mental arithmetic task.

5.3.1.0.1 *Performance (H1): Number of Subtractions & Accuracy Rate*

We did not find significant differences for neither of our performance measures (see Table 5.3). These findings suggest that participants' performance were not different across the three conditions; however slightly higher median values (i.e., higher number of subtractions) were observed in the Dog condition.

5.3.1.0.2 *Mean Heart Rate (H2)*

Figure 5.4(a) shows the mean heart rate values of all participants for the three minutes of relaxation period before the task and mean heart rate values for the three minutes during the task for each condition. As a manipulation check for our study setup, we compared participants' heart rate between each condition and the last three minutes of its relaxing period. We found significant differences for all three conditions, None, $t(29) = -5.79$, $\boldsymbol{p < 0.001}$, $d = 0.44$, Human, $t(29) = -4.00$, $d = 0.30$, $\boldsymbol{p < 0.001}$, and Dog, $t(29) = -3.64$, $\boldsymbol{p = 0.001}$, $d = 0.28$.

We calculated the change in heart rate between the relaxing period (i.e., the last three minutes) and its condition and then normalized them, so that all values would be positive. We did not find a significant main effect of support figure type on change in heart rate (see Table 5.3).

These findings indicate that participants' heart rate did increase during the task suggesting the potential impact of stress, but the presence or absence of the support figures did not impact participants' heart rate.

5.3.2 *Subjective Measures*

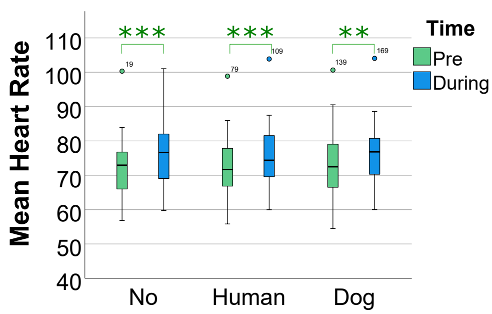
Table 5.5 summarizes the means/medians and standard deviations of our subjective results for the three conditions. Medians were reported for measures with data deviating from normality.

Measures	Timing	None	Human	Dog
Support Figure Evaluation	Post	5.07(1.34)	4.79 (1.24)	5.72 (0.94)
Preference (~)	Post	2.00 (0.79)	1.00 (0.88)	2.00 (0.66)
Perceived Stress (~)	Pre	2.00 (1.16)	2.00 (1.67)	2.00 (1.38)
	Post	3.00 (1.68)	3.00 (1.79)	2.50 (1.90)
Perceived Anxiety (~)	Pre	2.00 (1.24)	2.00 (1.87)	2.00 (1.48)
	Post	3.00 (1.84)	3.00 (1.85)	2.50 (2.03)
Perceived Difficulty (~)	Pre	5.00 (1.61)	4.00 (1.54)	5.00 (1.45)
	Post	5.00 (1.66)	4.50 (1.48)	5.00 (1.57)

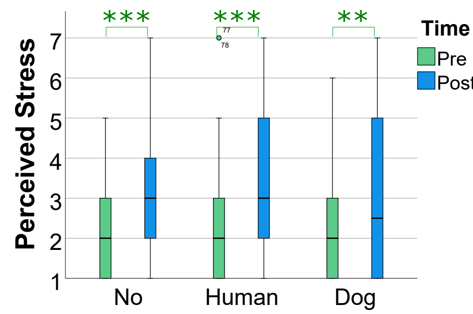
Table 5.5: Summary of the means/medians (standard deviations) for the pre and post/during objective and subjective measures for the three conditions. Medians were reported for measures with data deviating from normality and are marked with "(~)" next to appropriate measures. The terms *pre* and *post* are indicative of measures collected before and after the mental arithmetic task.

5.3.2.0.1 *Support Figure Evaluation (H3)*

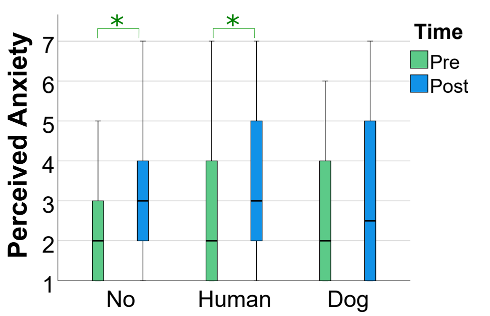
We computed average scores for questions SFE1 to SFE4 (Cronbach $\alpha = 0.8$) while reversing the negative item (see Table 5.1). Figure 5.5(a) shows the differences in participants' evaluations of the support figures. We found a significant main effect of support figure type on how positively participants evaluated the support figures (see Table 5.3). Pairwise comparisons indicated that participants evaluated the virtual dog support figure more positively compared to the virtual human or no support figure conditions.



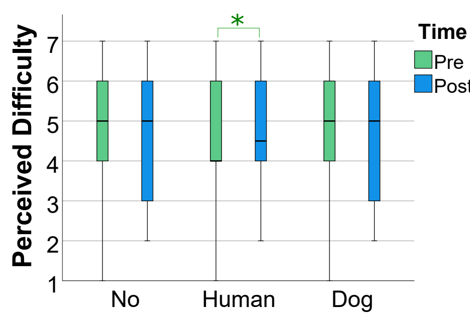
(a)



(b)



(c)

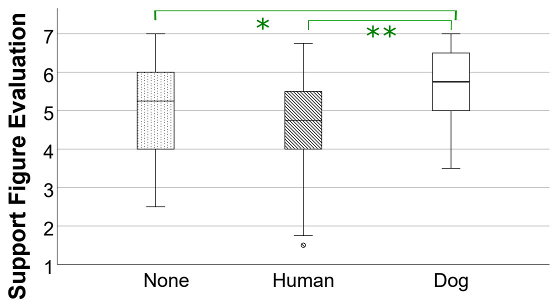


(d)

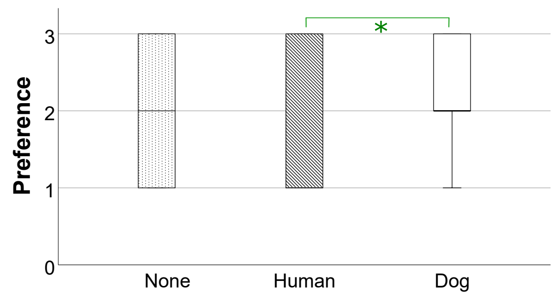
Figure 5.4: Box plots showing the pre and post results for (a) the mean heart rate values (in bpm) for the three conditions over the last three minutes of pre task (i.e., relaxation period) and task duration, (b) perceived stress, (c) the perceived anxiety, and (d) the perceived difficulty question. Lower scores indicate, lower mean heart rate, less stress, less anxiety, and lower perception of difficulty. Statistical significance: *** ($p<0.001$), ** ($p<0.01$), * ($p<0.05$).

5.3.2.0.2 Preference (H3)

Figure 5.5(b) shows participants' preference scores for each support figure type. After the experiment, we asked our participants to choose the conditions they most and least preferred based on how comfortable they felt in that condition. We ordered the three conditions based on their responses and gave a score of 3 to their most preferred condition, a score of 1 to their least preferred one, and a score of 2 to the condition in the middle.



(a)



(b)

Figure 5.5: Box plots showing the results for (a) the support figure evaluation questionnaire and (b) preference. Higher scores are indicative of a more positive evaluation and higher preference respectively. Statistical significance: ** ($p<0.01$), * ($p<0.05$).

Comparing these scores, we found a significant main effect of support figure on our participants' preference (see Table 5.3). Pairwise comparisons indicated that participants significantly preferred the virtual dog over the virtual human support figure; however no significant differences were observed between the virtual dog and no support figure conditions (see Table 5.3).

5.3.2.0.3 Perceived Difficulty (H3)

Figure 5.4(d) shows participants perceived difficulty pre and post each condition. We compared participants' response to the perceived difficulty question pre and post each condition. Comparison of pre-post perceived difficulty scores indicated that participants perception of task's level of difficulty increased in the virtual human condition while no significant differences were observed in the virtual dog and the no support figure conditions (see Table 5.3).

5.3.2.0.4 Perceived Stress and Anxiety (H4)

Figures 5.4(b) and (c) show participants' perceived stress and anxiety scores measured through the single-item stress question, and anxiety question. Comparing participants' responses to the single-item perceived stress question, we found that participants' perception of stress increased across all conditions regardless of the support figure type (see Table 5.3). Comparing participants' responses to the single-item perceived anxiety question, we found that participants' perception of anxiety significantly changed only in the virtual human and no support figure conditions with no significant changes in the virtual dog condition (see Table 5.3).

5.3.3 Qualitative Results

In this section, we present the themes that we identified from the thematic analysis of our participants' post-study interview responses. The percentages presented in this section are only indicative of what our participants described, therefore we can only infer the absence of a given point and not its opposite for the remaining participants for any percentages reported in the qualitative results.

5.3.3.0.1 Virtual Dogs are Perceived as More Supportive Than Virtual Humans

Overall, 63% of our participants mentioned that they appreciated the presence of one or both of the support figures and indicated feeling less stressed and being more comfortable in front of them (10 (33%) for Dog, 4 (13%) for Human, and 5 (17%) for both). In our qualitative analyses, we noticed a relationship between participants' perception of the support figures' "judgmental nature" and how comfortable they felt in their presence. Eight of our participants (27% of our participants) mentioned that they felt they were being judged or watched by the virtual human, while they mentioned the non-judgemental nature of the dog and thus a higher sense of comfort with it. The judgmental nature of the virtual human was often attributed to its human-like quality of being able to watch and assess and not her visual features being perceived as judgemental. Participants' perceptions that the dog was less judgmental than the human made them feel more comfortable about trying more math problems, even if they made errors.

> *P21: "The person [virtual human] has still some level of perception so they can judge ... the animal wouldn't perceive me any differently" P10: "the dog never judged even if I paused"*

In contrast, one participant that perceived the virtual human as non-judgmental and peer-like, felt disconnected with the virtual dog. Also, we noticed that participants that felt more comfortable with the virtual dog, usually associated this inclination to liking dogs or animals in general and a few noted the virtual dog's *presence* as being supportive.

> *P20: "I just like animals and they are peaceful"*

On the other hand, the comfort brought about by the virtual human was mostly attributed to her nodding behavior as participants felt like she is reassuring them about their performance.

> *P13: "I was more conscious of her [virtual human] approval"*

Overall, most participants preferred the presence of the support figures compared to not having any support figure, with the dog being perceived as more non-judgemental compared to the virtual human.

5.3.3.0.2 Virtual People are Perceived as More Interactive Than Virtual Dogs

Half of our participants (15 (50%) perceived the virtual human as more interactive than the virtual dog. On the other hand, nine of our participants (30% of our participants) described the virtual dog as less interactive and static. None of our participants made any comments about perceiving the virtual dog's head tilt/smiling as anthropomorphic, whereas they often mentioned the virtual human's behavior as being more engaging.

> *P30: "along with the fact that she was there, she was also nodding and smiling to like kind of you know keep me going"*

Interestingly, even though we designed the virtual human and dog to have the same level of interactivity every 12 seconds (see Section 5.2.2), some participants did not perceive the interactive nature of the virtual dog.

> *P25: "... the dog kind of just being there ... the dog was kind of just a focal point"*

We think the nodding behavior was perceived as more related to the participants' task. As a result, the virtual dog's expressions might have gone unnoticed since it did not seem to be directly related to the task at hand and merely positive.

5.3.3.0.3 Virtual Humans May be Perceived as Slightly more Distracting Than Virtual Dogs

Participants also mentioned being distracted by the support figures (4 (13%) Dog, 9 (30%) Human) at times. Interestingly participants mentioned the virtual human's nodding behavior as a source of distraction. We think that as the nodding behavior can be perceived more as a response to the participants' task, there is a chance that it attracted their attention and potentially distracted them from the task. Although in high-stakes tasks distraction can have negative consequences, one of our participants perceived the distraction in a more positive light:

> *P30: "When the dog started its action I smiled ... I don't think that's necessarily like a bad thing ... you're doing a task and seeing something like that makes you like happy I guess and it would allow you to be more relaxed and think a little more clear"*

Three participants (10% of our participants) perceived the support figures as focus points, helping them to concentrate and pay less attention to the panel when no support figure was present. For instance, describing the condition where no support figure was present, one of our participants noted:

> *P30: "when I was alone it was hard I felt like really pressured ... It was just a lot of emptiness."*

5.4 Discussion

Overall, we observed that the *virtual dog* has potential as a support figure with a positive influence on our participants' subjective evaluations. In comparison, the *virtual human* did not provide the same level of support as found for the virtual dog. In our study, we did not find any effects of support figure type on performance and changes in heart rate. In the following, we discuss our findings in more detail.

5.4.1 *Influence of Support Figure Type on Performance and Physiological Stress*

We did not find significant effects of support figure type of either performance measures rejecting our hypothesis **H1**. We think more research is required to better isolate and assess the effectiveness of the virtual support figures on performance as some of our participants reflected benefits for both virtual support figure types during the post-study interview. For instance, a few participants mentioned that the increased sense of comfort and the non-judgemental nature of the virtual dog encouraged them to make more subtractions with some participants referring to the dog's presence rather than its behaviors. Interestingly, previous research suggest that the mere presence of real dogs can have stress reducing effects [267], which might explain the positive outlook of some of the participants in the virtual dog condition even when it's positive behaviors were overlooked. On the other hand, participants described the behaviors of the virtual humans as either negative (e.g., being judged, discouraged, or distracted), or positive (e.g., reassured, encouraged) in relation to their performance. This might suggest that part of their attention was given to interpreting the virtual human's behavior, which potentially can lead to more distraction, while some participants overlooked the virtual dog's behaviors and only referred to its presence which may have led to lower distraction levels.

Also,we found no significant differences between the heart rate values for the different conditions, i.e., not supporting Hypothesis **H2**; however, we noticed that for all conditions participants' heart rate increased from the last three minutes of the relaxing period before each condition. Although our setup was inspired by previous social support studies (see Section 2.1.1) for inducing acute stress, based on our experimental conditions we cannot isolate the exact source of the increase in heart rate (e.g., somatic, cognitive, etc. [252]). We think that in the future, exploring other stressful tasks such as the cold pressor task tested by Allen et al. [9] which does not have the cognitive aspect may help with isolating the source of increase in heart rate.

5.4.2 Influence of Support Figure Type on Subjective Evaluations

Looking at our participants' support figure evaluation scores, we found significant differences between the virtual dog and the other conditions (see Figure 5.5(a)). Neither the virtual human nor the no support condition was evaluated as positively as for the virtual dog. This finding supports our Hypotheses **H3** and suggests that with our current comparisons, the virtual dog in AR was deemed as a more effective support figure which is similar to findings with real dogs [46, 206]. Hypothesis **H3** was also supported by our participants' preference of the virtual dog over the virtual human and backed up by their qualitative comments describing being more relaxed and comfortable in front of the dog.

Moreover, we found a significant increase in participants' perception of task difficulty in front of the virtual human, while this effect was not observed with the virtual dog and the no support figure conditions. With research suggesting virtual agents' ability in replicating social effects similar to real humans [177, 268], we think that findings from the social inhibition theory with real and virtual humans [177, 251] may explain this as serial subtraction is considered as a difficult task. In the virtual human condition, the presence of two people (i.e., the panel member and the virtual human) who were observing the participants, might have doubled the effects of social inhibition, resulting in the task being perceived as more challenging. Additionally, 8 of our participants perceived the virtual human as judgemental while viewing the virtual dog as less judgemental and associated this effect to the virtual human's ability of being able to watch and assess them and not her visual features. This perception might have increased the effects of social inhibition, as research on virtual agents suggests that the perception of judgemental nature may lead to the need for *impression management*, which can result in involving more of a person's mental resources [114, 160, 203]. However, deeper investigations are required to pinpoint whether the perceived non-judgmental nature of the virtual dog is due to the fact that it is realized as a dog, with real dogs known for their non-judgmental nature towards their human companions [46] or is it the case that any non-human virtual support figures can have such a non-judgmental quality. Overall, a larger sample size is required to deduce the absence of perceived difficulty for the virtual dog and the no support figure conditions with certainty.

Concerning perceived stress we found significant increases in participants' perception of stress measured through the stress question rejecting part of our Hypothesis **H4**. For perceived anxiety, we only observed significant increases for the virtual human and no support figure conditions and not for the virtual dog condition. These findings, partly support our Hypothesis **H4**, aligned with previous social support and animal-assisted activity research on real dogs suggesting lower stress levels with these entities [25, 119]. We speculate that the mental arithmetic task may have overshadowed the effect of support figures as in our setup similar to some past social support studies the support figures were present during the task [9, 60, 88]. We think that a larger sample size and exposing participants to the support figures only before the task may provide a clearer picture on the difference of the virtual support figures in terms of perceived stress and anxiety.

5.4.3 Limitations and Future Work

Our study population had certain limitations. Our sample size of 30 estimated through G*Power (3 × 1 within subjects design, $\alpha = 0.05$, Power = 0.8) [84], allowed us to detect medium effects sizes as low as 0.37. However, this limitation only applies to one of our comparisons (effect size = 0.31). Thus, non-significant effects with a medium effect size (<0.37) should be retested with a larger sample size in the future. Also, the majority of our participants were male and it is important to note that equal male/female distribution would provide a more accurate picture of the effectiveness of the virtual support figures.

Even though our participants mentioned being more stressed in the no support figure condition as they were watched by the experimenter (in her role as a panel member), it is possible that a completely unfamiliar person who participants had no other interactions with during the study could have exacerbated their experienced level of stress. Additionally, as our experimental setup was an adaptation of the Trier Social Stress Test [133] we did not vary the presence of the panel and therefore did not intend to investigate the effects of their presence. However, it is valuable to gauge the level of influence presented by the judging panel in such setups when the support figures are virtual in the future.

Also, opting for a forced approach for the preference rating may have limited our understanding of our participants' true preferences as we did not allow for multiple choices. Although, our participants' preference ratings are aligned with some of our other measures that participants were allowed to state their preference for any or no condition (e.g., support figure evaluation, open-ended interview responses), it is important to utilize and study less restricting approaches in the future and measure the potential differences between forced and unforced approaches on user preference.

Separately, in our experiment, the expressions exhibited by the support figures were happening randomly, and potentially performance-related feedback can lead to different results. Further research is required to investigate the influence of such random expressions with more user-centered ones, such as mimicry and playback tested by Zhang et al. [276]. Also, although our participants who found the virtual human to be judgmental, compared to the virtual dog, attributed this to the human-like capabilities of this support figure (i.e., the ability to watch and assess) and not the specific visual features of this character, it is important, to pretest virtual characters for the effects of anthropomorphism, gender, uncanny valley, and judgmental nature as factors that can potentially influence the effectiveness of social support figures in the future.

Moreover, we applied the findings on the benefits of real human support figures with positive expressions [60] to our virtual dog through the smiling and head tilting behavior as positive expressions [10, 18, 156]. Also, we placed the virtual dog on several virtual books to ensure that participants' viewing angles stay the same across support figures. These choices can introduce potential ambiguities with regards to the virtual dog being perceived as anthropomorphic or its head tilting behavior as a sign of confusion. Although, our participants did not mention anthropomorphizing the dog, it is important to study the impact of these choices on the quality of support participants may receive in the future. To this point, the impact of more realistic settings (e.g., dog lying on the floor and relaxed) and neutral expressions compared to positive ones can shed light on the contributing characteristics of virtual dogs as support figures.

Following the guidelines of previous literature, we recruited participants who did not have a dog phobia and dislike dogs in general [23, 206]. This choice may have resulted in our participants having a more positive attitude towards pets and animals (i.e., higher PAS scores) and our results only apply to a population with affinity towards dogs. Still, our sample is more neutral compared to pet-ownership percentages in the world (57% of consumers [202]) and the US (67% of households [12]). We felt that those who dislike dogs might not like to choose to receive social support from a virtual dog; hence we focused our attention on a population that has a higher chance of experiencing any benefit from such an interaction. Similarly, we felt that it would not be ethical to recruit individuals with dog phobias; therefore, other support figure types can be explored for this population.

Last, with advances in technology allowing for more personalized interactions, it is important to explore the realization of virtual support figures based on user preferences. For instance, virtual support figures can be presented as users' favorite cartoon characters or super heroes allowing for investigations on the relationships between user preference and concepts correlated with social support such as non-evaluative nature of support figures.

5.5 Conclusion

In this chapter, we described a human-subject study with a stressful mental arithmetic task aimed at understanding the potential of virtual animals in AR as social support figures, and their influence on a person's task performance, perceived stress, and subjective evaluations. In our experiment, participants were presented with three conditions: a virtual dog support figure, a virtual human, and no support figure. Our mixed-methods analysis revealed that participants evaluated the virtual dog support figure more positively than the other conditions. Also, the virtual dog received higher scores in terms of preference compared to the virtual human support figure. Emerged themes from a qualitative analysis of our participants' post-study interview responses shed light on the relationship between sense of comfort and perception of judgement, and the influence of support figure's interactivity. Although we did not find an effect of condition on participants' heart rate, we observed a significant increase of heart rate for all three conditions during the task.

CHAPTER 6: VIRTUAL DOGS AS DIEGETIC ATTENTION GUIDANCE MECHANISMS IN 360-DEGREE EXPERIENCES

This chapter presents a human-subjects user study investigating the Behavior and Expression aspect of the Human Effects category presented in Chapter 1. Additionally, this chapter captures the Behavior and Traits aspect of the five Research Considerations identified in our systematic literature review [189] represented through the presence or absence of behaviors of the virtual dog in acknowledgment of the virtual environment and the participants. These Research Considerations are applied to the context of diegetic attention guidance in 360-degree VR experiences where the virtual dog is compared with different types of diegetic and non-diegetic attention guidance mechanisms.

The thesis statements supported by this chapter are as follows:

- **[TS1] Entity-Self:** The presence of a virtual dog with dog-like behaviors can induce subjective changes within *real human interactants*, including:
  - **[TS1.3]** Enhanced attention guidance-related user experience and reduced fear of missing out
- **[TS3] Behavior-Self:** The simulated responsiveness of a virtual dog with dog-like behaviors can induce subjective change within *real human interactants*, including:
  - **[TS3.2]** Enhanced attention guidance-related user experience and increased preference

This chapter largely incorporates a previous peer-reviewed publication: "Virtual Animals as Diegetic Attention Guidance Mechanisms in 360-Degree Experiences," authored by Nahal Norouzi, Gerd Bruder, Austin Erickson, Kangsoo Kim, Jeremy Bailenson, Pamela J. Wisniewski, Charles E.

Hughes, and Gregory F. Welch. This work has been presented at and published in the proceedings of the IEEE International Symposium on Mixed and Augmented Reality [188].

6.1 Overview

360-degree experiences such as cinematic virtual reality and 360-degree videos are becoming increasingly popular. In most examples, viewers can freely explore the content by changing their orientation. However, in some cases, this increased freedom may lead to viewers missing important events within such experiences. Thus, a recent research thrust has focused on studying mechanisms for guiding viewers' attention while maintaining their sense of presence and fostering a positive user experience. One approach is the utilization of diegetic mechanisms, characterized by an internal consistency with respect to the narrative and the environment, for attention guidance. While such mechanisms are highly attractive, their uses and potential implementations are still not well understood. Additionally, acknowledging the user in 360-degree experiences has been linked to a higher sense of presence and connection. However, less is known when acknowledging behaviors are carried out by attention guiding mechanisms. To close these gaps, we conducted a within-subjects user study with five conditions of no guide and virtual arrows, birds, dogs, and dogs that acknowledge the user and the environment.

Through our user study we aimed to answer the following research questions:

- **[RQ1]** Are virtual animals a suitable **diegetic** realization for attention guidance mechanisms compared to non-diegetic ones in terms of user experience factors?
- **[RQ2]** Are virtual animals that **acknowledge** the user and its environment more effective than those without acknowledging behaviors in terms of user experience factors?

The findings of this chapter support **TS1** and **TS3**, as we found that the simulated responsiveness of the virtual dog improved our participants' sense of presence and contributed to a significantly more positive user experience compared to the other attention guidance mechanisms. Also, the qualitative analysis of our participants' post-study interview responses revealed themes detailing the positive influences of attention guidance mechanisms that belong to the environment and/or the story and are responsive towards the user and the environment.

6.2 Experiment

In this section, we describe the experiment we conducted to understand and compare the effectiveness and influence of attention guidance mechanisms in 360-degree immersive experiences.

6.2.1 Participants

We recruited 28 participants (10 male, 18 female, age 18–28, M = 21.21, SD = 2.84) affiliated with our university. Our experimental protocol was approved by the Institutional Review Board of our university. All of our participants had normal hearing and normal or corrected vision with glasses or lenses. 17 participants were single/multi pet owners, with 13 dog owners, 6 cat owners and 3 mice/hamster owners. At the end of the study, using a 7-point scale (1 = novice/not familiar, 7 = expert/very familiar), we asked our participants to rate their expertise with computers (M = 4.96, SD = 1.34), VR (M = 4.32, SD = 2.17), AR (M = 4.14, SD = 2.17), virtual humans (M = 5.32, SD = 1.80), and virtual animals (M = 4.78, SD = 1.91). Among the participants who had experience with virtual animals in video games, 18 of them mentioned that they experienced them in companionship or pet-like roles, three in guiding roles, and one in enemy/hunting roles. Participants were screened for dog and bird phobias before arrival.

6.2.2 *Materials*

Here, we present the details of our physical setup for our 360 VR experience, the virtual environment, the virtual events designed as attention guidance targets, and the different attention guidance mechanisms.

6.2.2.1 *Experimental Setup*

In our experiment, participants were seated and immersed in a virtual neighborhood via an HTC Vive Pro HMD (refresh rate: 90 Hz, resolution: 1440×1600 pixels, FoV 110°) which was connected to a workstation (Intel Xeon 2.4 GHz processors comprising 16 cores, 32 GB of main memory and two Nvidia Geforce GTX 980 Ti graphics cards). We used a separate computer for participants to answer questionnaires. We used Unity version 2019.2.13f1 for all of our development. Participants were told that they can freely explore the virtual neighborhood by changing their orientation and without the ability to translate to observe the life of its inhabitants, while in some trials they may see a virtual entity guiding them towards events, which may or may not interest them. Due to the free exploration nature of the study they could choose to ignore or follow the guide.

6.2.2.2 *Virtual Environment*

We used an urban neighborhood scene by Art Equilibrium that is available through the Unity Asset Store[1]. To create the illusion of a real neighborhood, we populated the scene with 13 simulated sentient characters with idle behaviors, such as walking and talking. See for example Figure 6.1.

[1] `https://assetstore.unity.com/packages/3d/environments/urban/japanese-street-170162`

Figure 6.1: Screenshots showing examples of some of the idle characters present in the virtual neighborhood.

We acquired the idle characters and their animations from Adobe Mixamo[2] and the Unity Asset Store[3]. All the walking virtual humans had spatial footstep sounds from Fesliyan Studios[4] and we played an urban distant ambient sound through the headphones, provided by ZapSplat[5].

[2] `https://www.mixamo.com/#/`

[3] `https://assetstore.unity.com/packages/3d/characters/animals/animal-pack-deluxe-v2-144071`

[4] `https://www.fesliyanstudios.com/royalty-free-sound-effects-download/footsteps-31`

[5] `https://www.zapsplat.com/`

6.2.2.3 Attention Guidance Mechanisms

In our experiment we investigated the effectiveness of four different attention guidance mechanisms, comparing them with each other and a no-guide condition. Our attention guidance mechanisms illustrated in Figures 6.2 and 6.3 were either a virtual arrow, a virtual bird, a virtual dog, or a virtual dog with acknowledging behavior. Each mechanism started its guidance routine 10–12 seconds after the start of the condition or after the end of each event. This guidance routine was repeated five times for each condition.

Figure 6.2: Illustrations of the attention guidance mechanisms for the 360-degree experiences we compared and evaluated in this chapter, from left to right: no guide, arrow, bird, and dog.

The first three mechanisms only directed the user to a target event and were not programmed to have any acknowledging behaviors towards the user or the environment. Therefore, we will refer to these three together as *non-acknowledging* mechanisms. For the non-acknowledging mechanisms, the guiding routine consisted of a mechanism spawning at 90 degrees to the left of the user's forward vector and travelling on an arc path around the user with the radius of 2.5 meters (i.e., within social space range [102]) at the speed of 30 degrees per frame. After arriving at their target event, all non-acknowledging mechanisms turned towards the event, after which they faded away.

We modeled the virtual bird[6] after a Blue Jay with a flying animation, and scaled it to be close

[6] https://assetstore.unity.com/packages/3d/characters/animals/birds/

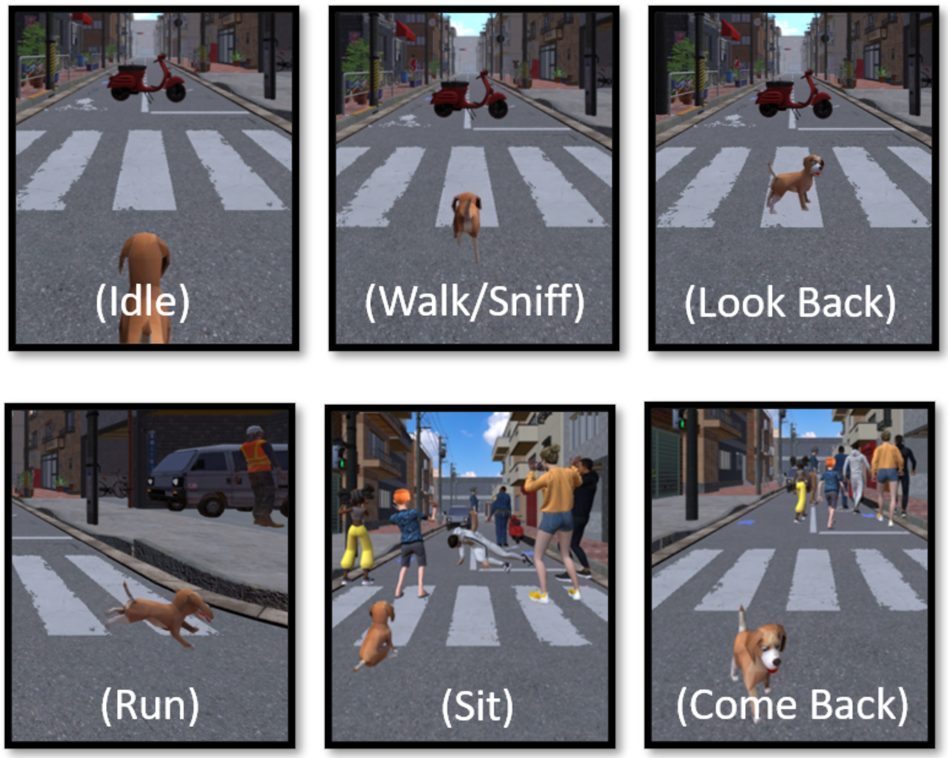


Figure 6.3: Screenshots showing the different diegetic behaviors and stages of the acknowledging dog's attention guidance mechanism.

to a real one [2] (30 cm head to tail, 52 cm wing to wing). We scaled the virtual arrow[7] to have the same length as the Blue Jay (i.e., 30 cm), with its widest and tallest part at 11 cm and 18 cm, respectively. Both the arrow and the bird traveled at one meter above the ground (i.e., roughly the vertical center of the FoV), which is similar to previous examples of flying arrows and animals/insects [53, 226]. We modeled the virtual dog [8] after a beagle, and scaled it to be close to a real beagle (30 cm shoulder height, 18 cm wide, 50 cm long) [77]. The non-acknowledging virtual dog was animated to run towards its target event, where it turned idle and faded away.

living-birds-15649

[7]https://assetstore.unity.com/packages/tools/particles-effects/arrow-waypointer-22642

[8]https://assetstore.unity.com/packages/3d/characters/animals/mammals/dog-beagle-70832

Although fading away is not a natural behavior for animals, to maintain consistency among the non-acknowledging mechanisms, we used the same means of leaving the experience for these entities, in line with related work on fading in attention guidance [226, 259]. Also, in pilot tests we observed that any extra movement/behavior by these mechanisms, such as moving out of the user's FoV, moving towards the horizon or towards the user would unintentionally induce the impression that the user is still being guided, which can be avoided with the fading mechanism.

We used the same 3D model for the *acknowledging* dog; however we randomized the color of the dogs between dark brown and light brown throughout the study. We programmed the acknowledging dog to stay 1 meter away from the user (i.e., within personal space range [102]) facing forward, and cycled it through idle animations of looking around while wagging its tail and scratching its ears. The presence of this dog close to the user was the first indication that this dog acknowledges the user as if it is *with* the user. We also programmed the acknowledging dog to remain in the user's FoV, and to walk towards its initial position when the user turned. For this mechanism, the guidance routine consisted of the dog leaving its position next to the user, sniffing the ground while walking 2.5 meters forward (i.e., acknowledging the environment), then fully turning clockwise and looking back at the user (i.e., acknowledging the user). With the acknowledging dog positioned on the arc path, similar to the non-acknowledging mechanisms, it ran on that path towards the position of a target event and turned towards the event after arrival. Unlike the non-acknowledging mechanisms, it sat down and observed the target event (i.e., acknowledging the environment). After the target event ended (see Section 6.2.2.4), the acknowledging dog turned and walked back towards the user (i.e., acknowledging the user) and turned again to its initial orientation facing the environment.

6.2.2.4 Target Events

In addition to the idle characters in the virtual neighborhood we implemented different target events that were intended to be more distinct and salient compared to the interactions of the idle characters. The events were programmed to be in one of the categories of a single person exercising, two people exercising, two people dancing, 5 people dancing, and three children playing/miming. As we wanted to maintain the similarity of the events within each category while ensuring that participants are not seeing the same characters(s) doing the same thing(s) every time, we implemented five different events for each category that are conceptually similar. This resulted in 25 events in total. For instance, for the single person exercising category, different virtual characters were programmed to do five different exercise routines (e.g., jumping jacks and boxing exercises). Figure 6.4 illustrates one example of each of the event categories. The event characters and their animations were acquired from Adobe Mixamo.

In the experiment, we randomly placed all target events six meters (i.e., within public space range [102]) directly behind the participants in a randomized range of ± 20 degrees. We set the *beginning* of the event animation (e.g., dancing) to start 5.8 seconds after it appeared, and the *ending* 10 seconds later. It took all guidance mechanisms roughly 5.8 seconds to arrive at the event, using about the same basic arc path, traversal speed and angles around the user (see for example Figure 6.2), while the acknowledging dog used the idle time before, during, and after the events for its supplemental diegetic acknowledging behaviors.

Figure 6.4: Screenshots of example target events from each of the five event categories, from left to right: single person exercising, two people exercising, two people dancing, a group of people dancing, kids playing.

6.2.3 Methods

In this section, we present the details of our experimental design and procedure, our hypotheses inspired by previous literature, and our quantitative and qualitative measures.

6.2.3.1 Study Design

We utilized a within-subjects design for our experiment with one factor (5 levels). We chose attention guidance mechanism as our independent variable (see Figure 6.2), which was realized in the following conditions:

- **No Guide [None]**: control
- **Arrow:** non-diegetic and non-acknowledging
- **Bird:** diegetic and non-acknowledging
- **Dog:** diegetic and non-acknowledging
- **Acknowledging Dog [Ack-Dog]:** diegetic and acknowledging

All participants experienced all five conditions and all five event categories (see Figure 6.4) within each condition. To account for order effects, Latin Square was used to randomize our study conditions, and although our event categories and the dog colors were designed to be comparable, we further randomized them between conditions to ensure no event category and no dog color is always seen with a specific condition.

6.2.3.2 Procedure

After the participants read the consent form, and provided their informed consent, we assigned them a participant ID and asked them to complete the Simulator Sickness Questionnaire [116]. We then briefed the participants on the general structure of the experiment and the free exploration nature of the study (see Section 6.2.2.1). We asked them to take a seat on a rotating chair in the middle of the experimental space, and helped them don the HMD. All of the participants started with a one-minute familiarization session during which they were immersed in the same virtual neighborhood that was used for the experimental conditions. Only the idle characters were present during this session. After confirming that they were ready, we started the first random condition assigned to the participant's ID. The beginning and end of each condition was communicated both with a beep sound heard through the HMD's headphones and was also verbalized by the experimenter. After each condition, we had the participant place the HMD on the chair and then answer several questionnaires on a computer. Participants completed the demographics and familiarity with technology questionnaires last. Afterward, participants took part in a post-study interview followed by monetary compensation.

6.2.3.3 Hypotheses

Here, we present our hypotheses focusing on the effectiveness of presence/absence of different attention guidance mechanisms and their influence on user experience, fear of missing out, and sense of presence. Our hypotheses are grounded in previous literature borrowing from findings on the use of attention guidance in 360 virtual experiences, and notions of diegesis and acknowledgment.

- **H1:** *Overt nature* of the non-diegetic arrow and the *acknowledgement* of the ack-dog will influence participants' behavior. (See Sections 2.4.1 and 2.4.3.)
  - **H1a:** The ratio of event visibility will be higher with the non-diegetic arrow, followed by the diegetic mechanisms and the no guide condition.
  - **H1b:** The ratio of mechanism visibility will be higher with the the acknowledging dog during the attention guidance period compared to the other mechanisms.
- **H2:** Utilizing the diegetic mechanisms will lead to a more positive *user experience* compared to the non-diegetic arrow and the no guide conditions. (See Section 2.4.2.)

- **H3:** Utilizing the acknowledging mechanism will lead to a more positive *user experience* compared to the non-acknowledging and no guide conditions. (See Section 2.4.3.)
- **H4:** The diegetic acknowledging mechanism will lead to a higher *sense of presence* and *user preference*, followed by diegetic mechanisms and the no guide, and the non-diegetic mechanism. (See Sections 2.4.2 and 2.4.3.)
- **H5:** Absence of any attention guidance mechanism will lead to higher levels of *fear of missing out*. (See Section 2.4.1.)

6.2.3.4 Measures

To assess the effectiveness of the different attention guidance mechanisms and investigate their influence on user experience and preferences we utilized objective behavioral data, subjective questionnaires, and a post-study interview which are detailed in this section.

6.2.3.4.1 Objective Measures

For each trial, we recorded the duration of time where the attention guidance mechanisms and the events where present in the participant's FoV at different stages resulting in the measures below:

- **Mechanism Visibility** Ratio: We calculated the duration the attention guidance mechanisms were in participants' FoV over the total duration of the guidance period (see Section 6.2.2.4). For non-acknowledging mechanisms, this duration started the moment they entered the participant's FoV. For the acknowledging dog, it started the moment it began running on the arc path towards the target event. For all mechanism the end of this duration was marked by the moment a guide arrived at the target event.

- **Event Start:** We marked whether the moment the events began were (e.g., characters started dancing) within participants' FoV. (See Section 6.2.2.4.)
- **Event Visibility** Ratio: We calculated the ratio of time an event was within participants' FoV over its total duration (i.e., 10 seconds), which indicates whether participants arrived at the event on time and/or how long they continued to observe the event.

6.2.3.4.2 Subjective Measures

We utilized multiple questionnaires to assess the influence of the attention guidance mechanisms on participants' subjective experience as detailed below.

- **Quality of Experience:** We utilized the short version of the User Experience Questionnaire (UEQ) [228] and an Attention Guide Questionnaire (AGQ) devised by the authors to assess the influence of the attention guidance mechanisms on the participants' quality of experience.
  - **User Experience Questionnaire (UEQ):** The UEQ-Short consists of eight items (semantic differentials). This questionnaire provides a *Total* user experience score and two sub-scales of *Hedonic* and *Pragmatic* qualities for all five conditions.
  - **Attention Guide Questionnaire (AGQ):** Table 6.1 shows the 13-item *Attention Guide Questionnaire* we devised to assess the effectiveness of the four diegetic and non-diegetic attention guidance mechanisms. The items of this questionnaire were inspired by related work on instruments to assess guidance mechanisms [183, 219, 231, 235]. The AGQ has four sub-scales of *Utility*, *Affect*, *Behavioral Influence*, and *Place & Plausibility Illusion*.
- **Presence:** We utilized the Slater-Usoh-Steed Presence Questionnaire [253] to assess participants' sense of *being there* in the virtual neighborhood.

Sub-Scale	Item
Utility	1*) I found the presence of this guide to be *distracting*. 2*) I found the presence of this guide to be *disruptive*.
Affect	3*) I found the presence of this guide to be *annoying*. 4) I found the presence of this guide to be *pleasing*. 5) I felt *encouraged to explore* the environment with this guide. 6) I felt like I had a *guiding companion*.
Behavioral Influence	7*) I *felt forced* to explore the environment with this guide. 8*) I *felt rushed* to explore the environment with this guide.
Place & Plausibility Illusion	9) This guide made me feel like I was *part of the experience*. 10) This guide was *aware of the environment*. 11) This guide was *aware of me*. 12) It felt as if the guide was *responding to me*. 13) The presence of this guide seemed *plausible* to the environment I was in.

Table 6.1: Attention Guide Questionnaire (AGQ). The sub-scales are: *Utility* (2 items), *Affect* (4 items), *Behavioral Influence* (2 items), and *Place & Plausibility Illusion* (5 items). Each question is assessed on a 7-point scale (1=not at all, 7=very much). Scales with an * are inverted for the analysis.

- **Fear of Missing out:** To assess the notion of *Fear of Missing out* [163], we utilized the questionnaire devised by MacQuarrie and Steed [163]. This questionnaire consisted of two sightly adjusted statements which are: (1) "At times, I was worried I was missing something," and (2) "My concern about missing something impacted my enjoyment of the experience." They were assessed on a 7-point Likert scale (1=strongly disagree, 7=strongly agree).

- **Preference:** We utilized a Preference Questionnaire devised by Wallgrun et al. [259] with slight adjustments. In the resulting questionnaire, participants were asked to order the five conditions according to six factors which were: (1) comfortable working with mechanism, (2) aesthetic appeal, (3) overall preference for future use, (4) recommend to others, (5) easy to learn and use, (6) least distracting.

6.2.3.4.3 Post-Study Interview

After the end of the experiment, we conducted a post-study interview to gain a better understanding of how the attention guidance mechanisms affected participants' perceptions and decisions. Specifically, participants were asked to describe which mechanisms were more or less comfortable to work with, aesthetically appealing, easy to understand, and distracting.

6.3 Results

We used a mixed-methods approach for the analysis of our results, which are detailed in this section. We used repeated measures ANOVAs at the 5% significance level for the analysis of most of our subjective and objective quantitative results in line with the ongoing discussion in the field of psychology indicating that parametric statistics can be a valid and informative method for the analysis of combined experimental questionnaire scales [180, 185]. We used paired sample t-tests with Bonferroni correction for the pairwise comparisons. This correction was applied to the p-values instead of adjusting the α level from 0.05. We confirmed the normality of the results using QQ plots and a Shapiro–Wilk test at the 5% level. Degrees of freedom were corrected using Greenhouse-Geisser and Huynh-Feldt estimates of sphericity when Mauchly's test indicated that the assumption of sphericity had been violated. Friedman tests were used to analyze the single item preference scores at the 5% significance level with Wilcoxon signed rank tests with Bonferroni correction for the pairwise comparisons.

Table 6.2 summarizes the main effects of the experimental conditions on our objective and subjective quantitative measures. The post-hoc tests are shown in Figure 6.5 and discussed below.

Measure	Main Effect
Objective Measures:	
Mechanism Visibility	$F(3,69) = 5.14$, $\boldsymbol{p = 0.003}$, $\eta_p^2 = 0.18$
Event Visibility	$F(4,92) = 11.81$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.34$
Event Start	$F(4,92) = 13.44$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.37$
UEQ:	
Total	$F(4,108) = 7.08$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.20$
Hedonic	$F(2.71,73.28) = 9.43$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.25$
Pragmatic	$F(2.76,74.53) = 4.38$, $\boldsymbol{p = 0.008}$, $\eta_p^2 = 0.14$
AGQ (Crobach α):	
Total (0.90)	$F(1.86,50.47) = 28.65$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.66$
Utility (0.84)	$F(1.94,52.42) = 8.47$, $\boldsymbol{p = 0.001}$, $\eta_p^2 = 0.23$
Affect (0.85)	$F(2.18,58.86) = 22.68$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.45$
Behavioral Influence (0.84)	$F(2.63,71.19) = 7.78$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.22$
Place & Plausibility Illusion (0.79)	$F(3,81) = 30.04$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.52$
Presence	$F(4,108) = 5.94$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.18$
Fear of Missing out	$F(2.88,77.99) = 8.01$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.23$
Preference:	
Comfortable Working with	$\chi^2 = 40.68$, $\boldsymbol{p < 0.001}$
Aesthetic Appeal	$\chi^2 = 51.34$, $\boldsymbol{p < 0.001}$
Future Use	$\chi^2 = 42.31$, $\boldsymbol{p < 0.001}$
Recommend to Others	$\chi^2 = 40.91$, $\boldsymbol{p < 0.001}$
Least Distracting	$\chi^2 = 36.08$, $\boldsymbol{p < 0.001}$
Easy to Learn and Use	$\chi^2 = 38.22$, $\boldsymbol{p < 0.001}$

Table 6.2: Summary of the main effects for the different objective and subjective measures.

6.3.1 Objective Measures

The results for the objective measures are shown in Figure 6.5(a). Due to technical issues with behavioral data recording in one of the conditions, the data of four participants was excluded from the objective measures analysis, leaving a total of 24 valid data sets. A summary of the main effects we found is shown in Table 6.2. We found significant main effects of the attention guidance mechanisms on all objective measures.

6.3.1.1 Mechanism Visibility Ratio

For the mechanism visibility ratio, we found a significant differences between the dog and ack-dog conditions (***p=0.011***), indicating that the ack-dog was in participants' field of view for a significantly longer duration during the attention guidance period.

6.3.1.2 Event Start

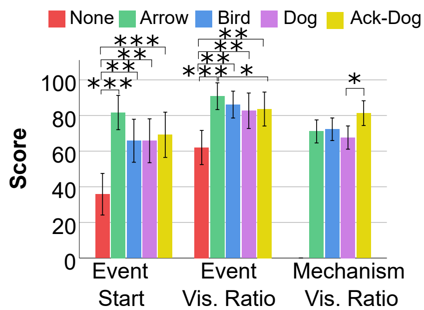
For the event start measure, we found significant differences between the no guide condition and all other conditions (all $\boldsymbol{p<0.01}$). This indicates that the start of events were significantly less often in participants FoV in the no guide condition compared to all other conditions.

6.3.1.3 Event Visibility Ratio

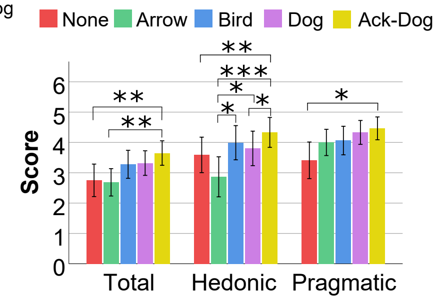
For the event visibility ratio, we found significant differences between the no guide condition and all other conditions (all $\boldsymbol{p<0.01}$), indicating that the events were in participants FoV for significantly longer periods with all the other conditions compared to no guide. We also found a significant difference ($\boldsymbol{p=0.04}$) between the arrow condition and the ack-dog condition, indicating that events were in participants' FoV for a significantly longer period compared with the arrow than the ack-dog.

6.3.2 Subjective Measures

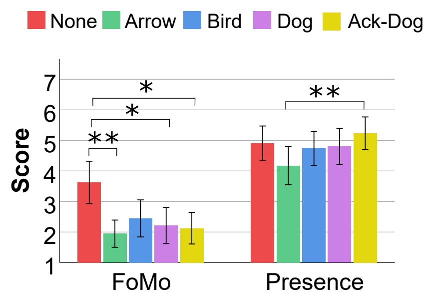
In this section, we report our results from the different subjective measures described in Section 6.2.3.4. A summary of the main effects can be found in Table 6.2. We found significant main effects of the attention guidance mechanisms on all subjective measures.



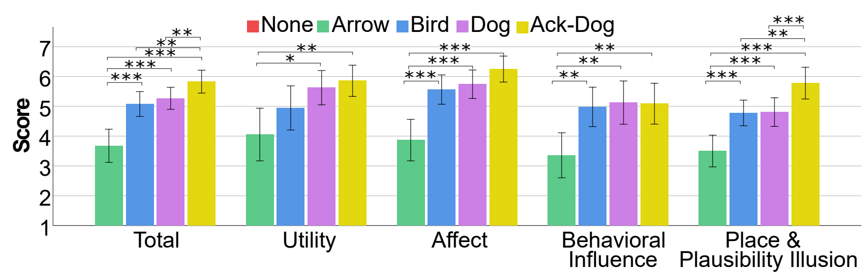
(a) Objective Measures



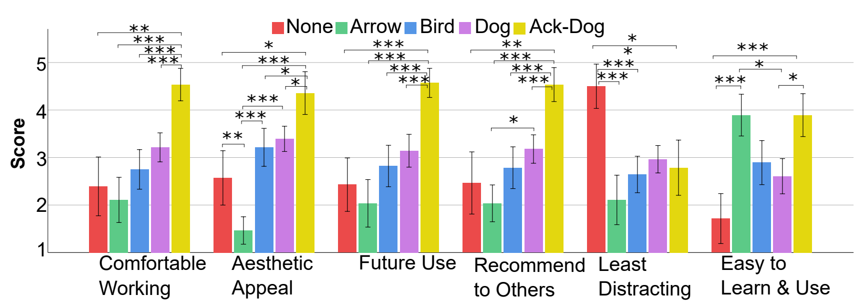
(b) UEQ-S



(c) FoMo and Presence



(d) AGQ



(e) Subjective Preferences

Figure 6.5: Objective and subjective results: (a) Objective Measures, (b) UEQ-S, (c) FoMo and Presence, (d) AGQ, and (e) Subjective Preferences. Bars indicate the mean score for each measure and error bars indicate 95% CI. Statistical significance: *** ($p<0.001$), ** ($p<0.01$), * ($p<0.05$).

6.3.2.1 Quality of Experience

6.3.2.1.1 User Experience Questionnaire (UEQ):

Figure 6.5(b) shows the results for the UEQ-Short questionnaire, specifically the total scores as well as hedonic and pragmatic sub-scales.

Pairwise comparisons between the *Total* scores revealed significant differences between the ack-dog and the arrow and no guide conditions (both $\boldsymbol{p < 0.02}$). These results suggest that overall, the ack-dog led to an improved user experience compared to the arrow and the no guide.

Pairwise comparisons between the *Hedonic* scores revealed significant differences between the arrow condition and the bird, the dog, and the ack-dog conditions (all $\boldsymbol{p < 0.04}$). Additionally, the ack-dog condition was significantly different from the no guide and the dog conditions (both $\boldsymbol{p < 0.02}$). These findings suggest that the ack-dog resulted in a more pleasant experience than the arrow, dog, and no guide conditions. The arrow resulted in the least pleasant experience.

Pairwise comparisons between the *Pragmatic* scores only revealed a significant difference between the ack-dog and the no guide conditions ($\boldsymbol{p=0.03}$). The results suggest that all mechanism were similar in terms of pragmatic qualities except the ack-dog being perceived as more pragmatic compared to the no guide condition.

6.3.2.1.2 Attention Guide Questionnaire (AGQ):

Figure 6.5(d) shows the results for the AGQ with its total score and four sub-scales. The scores were calculated by computing the means of the corresponding items after reversing the negative ones. Cronbach's alpha indicated a high internal consistency for the total scale and the sub-scales (see Table 6.2).

For the *Total* score, pairwise comparison indicated significant differences between the arrow condition and the bird, the dog, and the ack-dog (all $\boldsymbol{p < 0.001}$). Also, the ack-dog condition was significantly different from the bird and the dog conditions (both $\boldsymbol{p < 0.01}$). These results suggest that the non-diegetic arrow was perceived more negatively compared to the other conditions while the ack-dog was perceived more positively in its role as a guide.

For the *Utility* sub-scale, pairwise comparisons indicated significant differences between the arrow condition and the dog and ack-dog conditions (both $\boldsymbol{p < 0.02}$). These findings suggest that the diegetic mechanisms realized as dogs had a higher utility.

For the *Affect* sub-scale, pairwise comparisons indicated significant differences between the arrow condition and the bird, the dog, and the ack-dog (all $\boldsymbol{p < 0.001}$). These results suggest that the diegetic mechanisms resulted in more positive emotions compared to the non-diegetic arrow.

For the *Behavioral Influence* sub-scale, pairwise comparisons indicated significant differences between the arrow condition and the bird, the dog, and the ack-dog conditions (all $\boldsymbol{p < 0.01}$). These findings suggest that the non-diegetic arrow had a negative influence on participants' behavior in terms of feeling rushed and forced.

For the *Place and Plausibility Illusion* sub-scale, pairwise comparisons revealed significant differences between the arrow condition, and the bird, the dog, and the ack-dog (all $\boldsymbol{p < 0.001}$). Also, significant differences were found between the ack-dog, and the dog and the bird conditions (both $\boldsymbol{p < 0.01}$). These findings suggest that the arrow was perceived as the least plausible guide compared to all the other conditions while the ack-dog was perceived as the most plausible guide.

6.3.2.2 Fear of Missing out and Presence

Figure 6.5(c) shows the results for Fear of Missing out and Presence.

For *Fear of Missing out*, pairwise comparisons indicated significant differences between the no guide condition and the arrow, dog, and the ack-dog (all $\boldsymbol{p < 0.05}$). Overall, this suggests that having no guide introduced some level of concern with regards to missing the events.

For participants' sense of *Presence*, pairwise comparisons revealed that participants had a stronger sense of *being there* with the ack-dog compared to the arrow ($\boldsymbol{p=0.001}$).

6.3.2.3 Subjective Preference

Figure 6.5(e) shows the results for the subjective preference ratings. To calculate the scores for each preference factor introduced in Section 6.2.3.4, participants' preferences were transformed into ranking data by associating a score of five to their first choice, the score of four to their second choice and so on.

Pairwise comparisons for the *Comfortable Working with Mechanism* factor revealed significant differences between the ack-dog condition and the arrow, bird, dog, and the no guide conditions (all $\boldsymbol{p < 0.005}$). These findings suggest an overall high preference to work with the acknowledging diegetic mechanism realized as a dog compared to other alternatives.

Pairwise comparisons for the *Aesthetic Appeal* factor revealed significant differences between the ack-dog condition and the arrow, the bird, the dog, and the no guide conditions (all $\boldsymbol{p < 0.05}$). Additionally, we observed significant differences between the arrow condition and the bird, the dog, and the no guide conditions (all $\boldsymbol{p < 0.05}$). These results suggest that the acknowledging diegetic guide presented a more appealing experience compared to the others while the non-diegetic arrow was perceived as the least aesthetically appealing.

Pairwise comparisons for the *Overall Preference for Future Use* factor revealed that the ack-dog condition was significantly different than the arrow, the bird, the dog, and the no guide conditions (all $\boldsymbol{p < 0.001}$). These findings suggest that participants had a stronger preference to use the acknowledging diegetic mechanism in the future compared to the others.

Pairwise comparisons for the *Recommend to Others* factor revealed significant differences between the ack-dog condition and the arrow, the bird, the dog, and the no guide conditions (all $\boldsymbol{p < 0.01}$). Additionally, we found a significant difference between the dog and the arrow conditions ($\boldsymbol{p=0.01}$). These findings suggest that participants were more willing to recommend the acknowledging diegetic mechanism to others compared the rest of the conditions with a preference for the diegetic dog over the non-diegetic arrow.

Pairwise comparisons for the *Easy to Learn and Use* factor revealed significant differences between the ack-dog condition and the dog and no guide conditions (both $\boldsymbol{p < 0.02}$). Also, we found significant differences between the arrow and the dog and no guide conditions (both $\boldsymbol{p < 0.02}$). These findings suggest that participants perceived both the ack-dog and the arrow mechanisms as more understandable compared to the dog and the no guide conditions.

Pairwise comparisons for the *Least Distracting* factor revealed significant differences between the no guide condition, and the arrow, the bird, the dog, and the ack-dog conditions (all $\boldsymbol{p < 0.02}$). These findings suggest that compared to not having a guide, the addition of the four remaining mechanisms, regardless of their characteristics, distracted our participants.

6.3.3 Qualitative Results

In this section, we present the qualitative results of our participants' post-study interview responses. We used the thematic analysis approach devised by Braun and Clarke [44]. This analysis was conducted by the first author of this manuscript. The analysis consisted of transcriptions of post-study interview responses, iterative steps of data familiarization, identification of code words, conceptual grouping of code words into themes and refining the themes. The analysis revealed three themes and the effect of each theme on the quality of our participants' experience.

6.3.3.1 Blending in with the Environment Matters

18 of our participants (64%) described the notion of a guide blending in with the environment (i.e., being diegetic) as one of the main factors for preferring a mechanism over another. For instance, the non-diegetic arrow was described as unnatural, out of place, or forced reminding participants that the experience is not real, while the diegetic guides that *blended in* were described as more pleasing and less distracting. For instance, two participants stated:

> *P5: "... the dog that was with me the whole time, it was more aesthetically appealing because it seemed like it fit into the environment, more like a dog would really be there in that type of city and it made me feel more comfortable because it was there..."*

> *P24: "...how much it fits into the environment like the dog and bird ... with the animal guides they were still guiding me but it wasn't like I was on a leash with it, the arrow felt a little more force kind of like this where you need to go kind of format..."*

Additionally, the behaviors that defied the ability of a guide to blend in the environment played a role in their decisions. Although, the diegetic animals were preferred more, their disappearance, which can be considered a non-diegetic behavior, negatively influenced the experience of some of our participants (61%) either in terms of distracting them, reminding them that the experience is not real, or that they are not present in the virtual neighborhood. One participant remarked:

> *P20: "... I rated the arrow the lowest cause it kind of just reminded me that yeah I'm in a simulation something that shouldn't be here normally the animal companion ones*

were nice but when they disappeared they had the same sense of oh right I'm inside a simulated environment that fade out kind of pulled me out of things..."

6.3.3.2 Acknowledgment Led to a More Positive Experience

Our participants preferences were positively influenced by the acknowledging behavior of the diegetic dog and many of our participants (61%) noted that the the dog's behaviors towards them and the environment seemed natural and made them feel like they are actually there, introducing feelings of reassurance, companionship, and a sense of connection and communication. Two participants stated:

> *P9: "...I really enjoyed the dog who just stayed the entire time because he seemed more lifelike he would sit down look at it like a real puppy dog would do in reality and I really enjoyed that cause it made me feel connected to the space so it made me feel like oh this is realistic..."*

> *P19:"... it both moving around and yet kind of still feeling like a dog just kind of felt like okay it's a light little situation not anything to be worried about at all... it would catch my attention and yet still feel natural at the same time..."*

6.3.3.3 Positive Associations with the Guide Matters

20 of our participants (71%) noted that their affinity towards and familiarity with the animal guides affected their preference as they found them more appealing, cute, or elegant compared to the non-diegetic arrow even though the arrow was considered as more direct and easier to understand by many of our participants (60%). A participant noted:

P18: "... I really liked the bird I just thought it was pretty like as soon as I saw it I was like whow like I'm gonna go where ever that bird is going...I'm just familiar with having dogs around me and it makes me more comfortable having it there, like I wasn't alone I was with the dog even before I noticed that it was the guide..."

6.4 Discussion

In this section, we present our main findings and discuss the implications of utilizing attention guidance mechanisms that are diegetic and/or acknowledging on user experience and behavior.

6.4.1 Virtual Animals are Effective as Diegetic Attention Guidance Mechanisms (RQ1)

Primarily, our findings indicate the potential of virtual animals as diegetic attention guidance mechanisms compared to the non-diegetic arrow in enhancing participants' user experience. For instance, the UEQ results indicated an overall less positive experience with the non-diegetic arrow compared to the ack-dog, with the arrow receiving the lowest hedonic quality scores compared to all the other conditions. Also, we did not find any support for the arrow enhancing participants' experience compared to the no guide condition. These findings are also aligned with our devised attention guidance questionnaire (AGQ). Compared to the diegetic mechanisms, the non-diegetic arrow received the lowest total score, was perceived as most distracting/disruptive (i.e., the utility sub-scale), reduced positive affect and place and plausibility illusion, and was perceived as more forced (i.e., the behavioral influence sub-scale). These findings partly support our Hypothesis **H2** and indicate the potential benefits of utilizing diegetic mechanisms. Although the non-diegetic arrow was perceived as the most direct by many of our participants, making it a top candidate for fast and efficient guidance, it was evaluated very negatively. We speculate that participants' appreciation of the mechanisms that blended in with the environment and seemed more natural may have affected the evaluation of the non-diegetic arrow, especially in the presence of multiple sentient and interactive characters, exacerbating its lack of diegesis.

We did not find significant effects supporting that all of our diegetic attention guidance mechanisms can lead to a higher sense of presence compared to the non-diegetic arrow, not supporting parts of Hypothesis **H4**. Based on the qualitative analysis of our participants' post-study interview responses, we speculate that this is caused by the non-diegetic behavior of disappearance exhibited by two of our diegetic conditions, as participants characterized the disappearance of animals as unnatural.

Focusing on our participants' preference scores, the diegetic ack-dog was highly preferred for the majority of the factors which is discussed in Section 6.4.2 in more detail. A few exceptions were observed in the *Aesthetic Appeal* and *Recommend to Others* factors, as our participants chose the non-diegetic arrow as the least aesthetically appealing condition and preferred to recommend the diegetic dog compared to the non-diegetic arrow significantly more. These findings are aligned with previous positive perceptions of virtual animal/insect attention guides [53, 183], partially supporting our Hypothesis **H4**. As noted above, we speculate that the disappearance of the two diegetic virtual animals influenced their desirability and we propose further exploration for diegetic behaviors of such mechanism to successfully indicate the end of the guidance period without negatively influencing users' experience.

Aligned with Hypothesis **H1a**, all of the attention guidance mechanisms were found to be effective as their presence led to increased event visibility ratio and mean event start scores. This was also reflected in our participants' *Fear of Missing out* ratings, where the arrow, dog, and ack-dog mechanisms were evaluated more positively compared to the no guide condition. From this, we accept Hypothesis **H5**. However, we can only partially accept hypothesis **H1a**. Our expectation was that the overt nature of the arrow would make the presence of a target event more explicit to our participants. However, we only found a significant difference in visibility ratio between the non-diegetic arrow and the ack-dog. Also, the findings from the AGQ behavioral influence sub-scale show that the ack-dog was perceived as less forced compared to the arrow, which may have resulted in more exploration freedom with the ack-dog; hence, the lower event visibility ratio. However, we do not see a similar pattern with the other non-acknowledging diegetic conditions, which may have been influenced by their disappearance or their non-acknowledging behavior, requiring future investigations to pinpoint the exact cause.

6.4.2 Influence of Acknowledging Behavior for Attention Guidance Mechanisms (RQ2)

Overall, the ack-dog, which exhibited acknowledging behaviors towards the participants and the environment, resulted in a more positive experience compared to the no guide and the non acknowledging guidance mechanisms which is aligned with previous exploration on this topic suggesting the potential for an increased sense of presence, enjoyment, and connection [49, 231]. Focusing on quality of experience, UEQ scores indicated an overall increased positive perception of the ack-dog over the no guide and non-diegetic arrow, with a hedonic advantage over all conditions but the bird, and a pragmatic advantage over the no guide condition. The total score as well as the place and plausibility sub-scales of the AGQ revealed a significant advantage over all the other conditions, and the ack-dog was perceived as less disruptive/distracting (i.e., the behavioral influence sub-scale) compared to the arrow. Also, the ack-dog resulted in a significantly higher sense of presence compared to the non-diegetic arrow. These findings partly support Hypotheses **H3** and **H4**. We speculate that the increased place and plausibility illusion [235] induced by the ack-dog's behaviors and its continuous presence, which was deemed natural by our participants, increased the participants' perception of self-relevance and the ack-dog's social influence [38, 39], resulting in our participants' experience of a higher sense of presence, companionship, and connection captured in their subjective ratings and their interview responses. Additionally, these findings can explain why the ack-dog was significantly preferred more in many of the preference factors compared to all other conditions, such as *Comfortable Working with Mechanism*, *Aesthetic Appeal*, *Future Use*, or *Recommend to Others*, while only significantly different than the no guide and the diegetic dog in the *Easy to Learn and Use* factors partly supporting our Hypothesis **H4**.

Our expectation for hypothesis **H1b** was that the acknowledging behavior of the ack-dog might communicate that the ack-dog is aware of the goings-on in the environment, and with real dogs being more common in guiding roles [205, 261], participants may feel more encouraged to follow it more closely, leading to higher mechanism visibility ratios. However, while we see a trend for a higher mechanism visibility ratio for ack-dog compared to all other condition, this effect is only significant between the ack-dog and the non-acknowledging dog condition. For future studies, we think that using eye tracking can better distinguish the differences between the effectiveness of our attention guidance mechanisms, for instance by analyzing gaze fixation data.

6.4.3 Limitation

Our study has certain limitations. First, similar to many previous AR/VR attention guidance research, we adopted a holistic view of each attention guidance mechanism, where the defining characteristics of the mechanisms are not varied or studied consistently and are compared as a whole in favor of mechanism practicality [36, 42, 142, 183, 214, 226, 239]. We think that future research will benefit from adopting factorial design approaches to better narrow down on the impact of each characteristic which can augment the current more practical findings and lead to more systematic design decisions. Second, we did not explore various content types and we believe that there is a lot of opportunity in exploring the influence of content type on users' guidance mechanisms preferences and overall experience (e.g., entertainment vs. educational).

6.5 Conclusion

In this chapter we presented a within-subjects user study in which we compared the effectiveness of virtual animals as diegetic attention guidance mechanisms and the role of acknowledging behavior on participants' experience in 360-degree experiences. Our results indicate that diegetic mechanisms can positively influence participants' quality of user experience and effectively guide them towards target events. Additionally, the inclusion of acknowledging behaviors resulted in a higher sense of presence with participants preferring the diegetic acknowledging mechanism. A qualitative analysis of our participants' post-study interview responses further revealed three main themes influencing participants' preferences: blending in, acknowledging behaviors, and positive associations.

CHAPTER 7: VIRTUAL DOGS AS SOCIAL PRIMING STIMULI IN AUGMENTED REALITY

This chapter presents a human-subjects user study investigating the Social Effects aspect of the Human Effects category presented in Chapter 1 where the potential of virtual dogs as social priming stimuli for virtual humans is studied. Inspired by previous literature on social priming [68–70] and social catalytic effects of real dogs [30, 98, 169, 266, 270], we only focus on the Visual Representation aspect of the five Research Considerations identified in our systematic literature review [189] and compare social priming effects of social interactions with a virtual dog, a virtual human, a virtual robot, and a non-social priming condition where the virtual human is looking at her phone. The thesis statement supported by this chapter are is follows:

- **[TS2] Entity-Other:** The presence of a virtual dog with dog-like behaviors can induce positive affective changes within *real human interactants* towards *other virtual interactants*.

This chapter largely incorporates a manuscript that is submitted for publication at the time of this dissertation publication: "Virtual Humans with Pets and Robots: Exploring the Influence of Social Priming on One's Perception of a Virtual Human," authored by Nahal Norouzi, Matthew Gottsacker, Gerd Bruder, Pamela J. Wisniewski, Jeremy Bailenson, and Gregory F. Welch.

7.1 Overview

Over the past 20 years researchers have been studying social interactions between real humans and virtual humans (VHs) primarily by varying *VH-specific characteristics* or factors associated with a VH's *contextual existence* [190, 196]. By contextual existence we mean factors that aim to create the illusion that the VH is associated with its environment, and give context to its presence. For example, if a VH is affected by (or exhibits awareness of) events in the real physical environment, or is able to affect (influence) that environment, that reinforces the VH's association with its environment [127, 146]. If a VH shares lifelike *backstories* with users [33], or *socially primes* users by engaging in social interactions with other real/virtual human actors [68–70], that reinforces the VH's contextual presence. Previous research has found that the addition of social priming and backstories before users' primary interaction with a VH influences their subsequent interactions by enhancing their mood, engagement, and social presence with the VH [33, 68–70]. Both mechanisms are also practical: they can be incorporated into a wide range of existing interactions users may have with VHs, and both mechanisms can often be implemented via "canned" (pre-scripted) sequences.

While previous research found that social priming involving real/virtual *humans* seen interacting with a primary VH can positively influence perceptions of the VH, similar to Figure 7.1 at (a), it is unclear whether *non-humanoid* virtual actors seen interacting with a primary VH can bring similar benefits. The possibility of social priming with non-humanoid virtual actors is motivated by several factors. For example, increasing the number of virtual human actors may add complexities to the social dynamics as users may expect these virtual humans to go beyond just acting, and expect to interact with them, which is not always possible. Furthermore, it may be the case that a non-humanoid social actor is already present in the primary VH's space, conveniently removing the need to add another VH just for the sake of social priming.

One particularly interesting example of a non-humanoid virtual actor to facilitate social priming is a virtual dog. The use of a dog is inspired by the fact that they are commonly associated with humans, and there is extensive evidence of positive associations between dogs and humans. For example, researchers have found that real dogs can create a "halo" effect for their owners (e.g., more friendly/likable) and act as a social catalyst resulting in dog owners receiving more positive attention compared to non-dog owners [30, 98, 169, 266, 270]. Another potential non-humanoid alternative is a virtual robot, motivated by the years of research in social robotics where researchers study and develop social robots in the real world aimed at different applications such as companionship [87, 140]. Thus, we explored the following research questions:

- **RQ1** What are the subjective and objective influences of social priming compared to a non-social priming condition?
- **RQ2** Are the influences of social priming limited to VHs interacting only with other real/virtual humans?

The findings of this chapter support **TS2**, as our participants' attributed positive affects to the VH interacting with the virtual dog and were inclined to engage in further interactions with that VH. The qualitative analysis of our participants' post-study interview responses align with these findings as some of our participants noted feeling comfortable and positively surprised due to observing the virtual dog.

7.2 Experiment

This section presents details of our human-subjects experiment, including our study participants, methods, and materials.

7.2.1 Methods

This section explains the study design and procedure we adopted to explore the influence of social priming with different stimuli on participants' perceptions of different VHs and their overall experience.

7.2.1.1 Study Design

We carried out a within-subjects study using a 4×1 Latin Square design to counterbalance our conditions. Participants played a 20-questions guessing game with a different VH game partner (GAME-VH) across all four conditions. The specific GAME-VH and the answers for each round of the 20-questions guessing game were randomized, so no condition was associated with a specific GAME-VH or answer. In all of our conditions, participants walked to the doorway and waited until they were invited in by the GAME-VH. Our four study conditions are described as follows:

- **Social Priming:**

  Upon reaching the door, participants observed an ongoing social interaction between GAME-VH and one of three different virtual actors. After 16 seconds the virtual actor moved to the side but remained in the room as shown in Figure 7.1 at (e)–(g), and the GAME-VH invited the participant inside to play the guessing game. There are three social priming conditions corresponding to the three virtual actors.

  - **Virtual Human Stimulus (STIM-VH):** A virtual human used as the virtual actor.
  - **Virtual Dog Stimulus (STIM-DOG):** A virtual dog used as the virtual actor.
  - **Virtual Robot Stimulus (STIM-ROBOT):** A virtual robot used as the virtual actor.

- **Non-Social Priming (STIM-PHONE):**

  Upon reaching the door, participants observed GAME-VH in the process of looking at her phone. After 16 seconds GAME-VH invited them inside to play the guessing game. The duration of this non-social priming was chosen to match the stimuli exposure time for the three social priming conditions (above).

In addition to previous literature [30, 68–70, 87, 98, 140, 169, 266, 270], we chose our three social

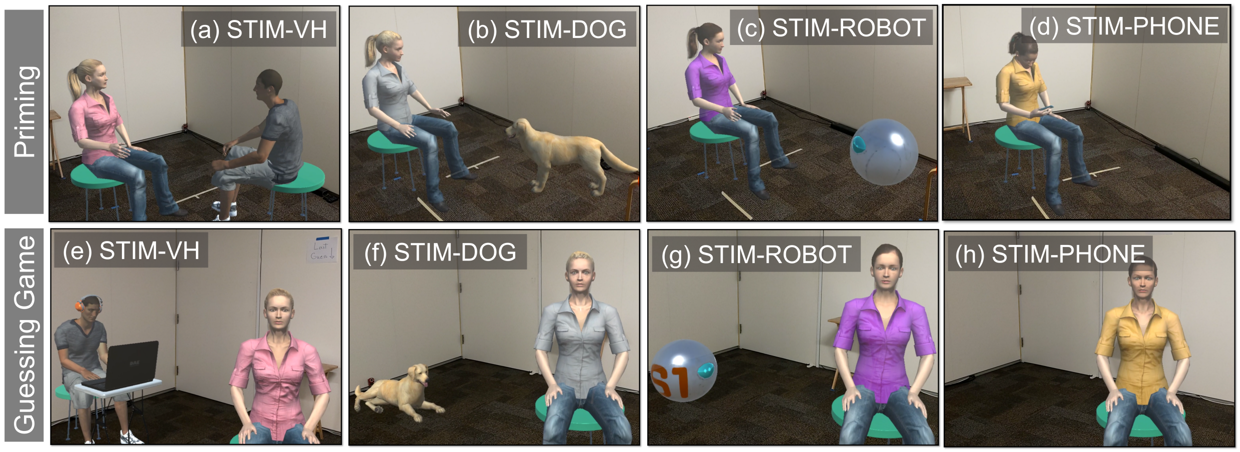


Figure 7.1: Screenshots from the participants' view through the head-mounted display. Top row showing the priming phase of the four conditions with participants standing at the doorway. Bottom row showing the 20-questions guessing game phase for each condition with seated participants facing their head in a way to fit both characters in (e) to (g).

priming virtual actors based on three criteria: an expectation they would be perceived as capable of (a) interactivity and (b) locomotion; and (c) they would fall into distinct classes of entities.

7.2.1.2 Procedure

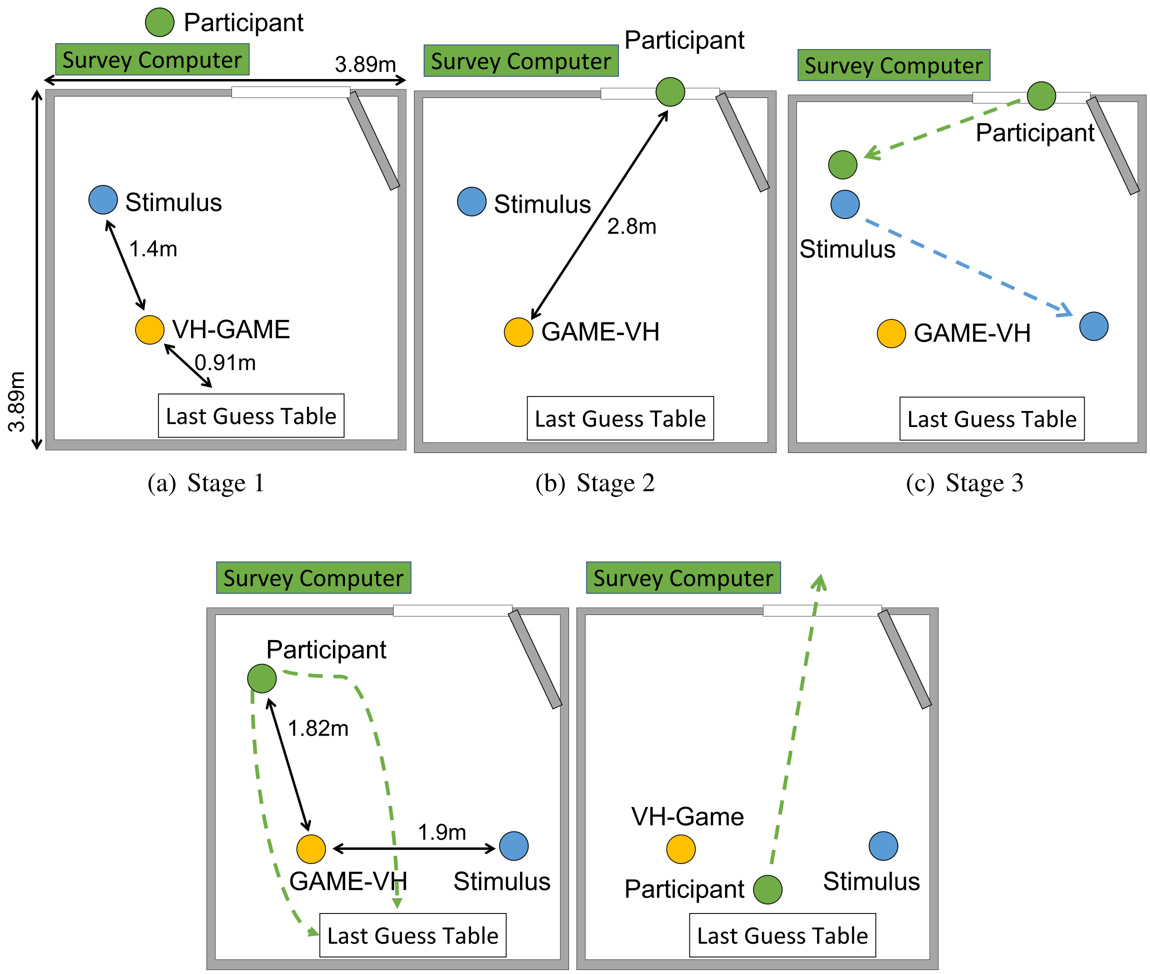
Participants were met in the lobby of our building and guided to the experimental space. After reading the informed consent document and consenting to take part in the study, the experimenter explained the general goal of the study, which is to evaluate the capabilities of augmented reality technology in facilitating social interactions with VHs, and noted that participants would play four rounds of the 20-questions guessing game in an augmented reality break room with four different VHs. Next, the experimenter asked the participants if they had played a 20-questions guessing game before and instructed them to phrase their questions based on yes/no answers. As part of the introduction to the game, participants were told that the GAME-VH could be thinking about anything such as famous people, specific types of food, places, animals, and electronic devices. Then the experimenter and the participants played a trial round to ensure everyone had a similar understanding of the game. Next, the experimenter explained the five stages of the experiment shown in Figure 7.2:

- **Stage 1:** Don the head-mounted display (HMD) after the experimenter's cue and move towards the doorway after hearing a bell sound through the HMD's speakers.
- **Stage 2:** Wait for GAME-VH to invite you in and have a seat.
- **Stage 3:** Follow GAME-VH's cues and start asking questions when prompted by GAME-VH and a second bell sound. Participants were told that the game would end after 20 questions or 3 minutes, whichever came first. Note that we chose difficult final answers (see Sec. 7.2.2.2) so participants always lost.
- **Stage 4:** If the game ends without having guessed the item chosen by GAME-VH, follow GAME-VH's prompt to write your last guess on a post-it on the table in the back of the room.
- **Stage 5:** Leave the room and then doff the HMD.

Participants answered several subjective questionnaires after each condition. After the last condition, participants answered technology familiarity and demographic questionnaires, followed by a short post-study semi-structured interview. Lastly, the participants were thanked for their participation and compensated for their time.

7.2.1.3 Participants

We recruited 24 participants (7 female, 17 male, age 18–37, $M = 24.17$, $SD = 5.18$) for our study. The study protocol was approved by the institutional review board of our university. We



(a) Stage 1 (b) Stage 2 (c) Stage 3

(d) Stage 4 (e) Stage 5

Figure 7.2: Illustrations of the physical setup with placement of the virtual entities at different stages of the interaction.

asked our participants to assess their familiarity and expertise with related technology by answering six 7-point scale questions (1 = novice/not familiar, 7 = expert/very familiar) capturing expertise with computers ($M = 5.5$, $SD = 0.88$) and familiarity with VR ($M = 5.17$, $SD = 1.31$), AR ($M = 4.71$, $SD = 1.46$), VH agent/avatars ($M = 5.13$, $SD = 1.54$), virtual animals ($M = 4.71$, $SD = 1.68$), and virtual robots ($M = 4.42$, $SD = 1.64$). Nine participants were single or multi-pet owners (five cats and nine dogs in total). Eleven participants had normal vision, nine had corrected vision with glasses, and two had corrected vision with contact lenses.

7.2.2 Materials

This section describes the details of the physical space, virtual entities, and the 20-questions guessing game utilized in our augmented reality experiment. Figure 7.2 depicts the physical setup and the distances between things.

7.2.2.1 Experimental Setup

We used a HoloLens 2 HMD (frame rate: 60 Hz, diagnoal field of view: $54°$, and resolution: 2048×1080 per eye [3, 106]) and two graphics workstations (Specs: Intel Xeon 2.4 GHz 16-core processor, 32 GB of main memory, and two Nvidia Geforce GTX 980 Ti graphics cards). The participants used one workstation to answer questionnaires and the recording of the post-study interview. The experimenter used the other workstation for running a server application that logged data and controlled the behavior of the virtual entities on a client application on the HMD. All the server/client applications were created using the Unity graphics engine version 2018.4.34f1. Participants played the 20-questions guessing game while seated on a stationary stool in a $3.89\,\text{m} \times 3.89\,\text{m}$ experimental room with the door open. The black arrows in Figure 7.2 show the distance estimates between participants and the different virtual entities at different phases of each condition. It is important to note that given the field of view of the HMD, if participants were directly facing the VH game partner in Stage 3 of the interaction (see Sec. 7.2.1.2) they could only catch a glimpse of the social priming stimuli in the corner of the room by moving their head.

7.2.2.2 20-Questions Guessing Game Phase

We used a 20-questions guessing game as the context for the social interaction between participants and the GAME-VHs as this game has been effectively used in previous human-agent interactions [21, 70, 145]. To control for the potential impact of the game results on participants' perceptions of the GAME-VHs, we structured the questions so that participants would always lose. To ensure the loss we randomly assigned one of four relatively challenging final answers (difficult to guess) to each condition, and allowed the experimenter to adapt the GAME-VHs' responses throughout (see Table 7.1). The four final answers were: Brad Pitt as a famous actor, the Sydney Opera House as a place, Lasagna as a food item, and Condor as an animal.

7.2.2.3 Virtual Entities

This section details all the virtual entities that the participants observed and/or interacted with in each of the four conditions. For all of the virtual entities detailed below, we used a combination of pre-made animations from the creators of the virtual entities, Adobe Mixamo [5] animations, and custom animations created in Unity's animation window.

*7.2.2.3.1 Virtual Human Game Partner (*GAME-VH*)*

We adopted four different female GAME-VH models from the Microsoft RocketBox Avatar Library library [173]. As we wanted to limit the influence of the GAME-VHs' facial features or clothing styles on the participants' perceptions, we used four different GAME-VHs that each had similar facial features, and were wearing similar clothing, but had different colored shirts as shown in Figure 7.1. We added blendshapes to the GAME-VHs using Autodesk Maya 2022 [20] to control their facial expressions and lip movements while talking. We used Rogo Digital Lip Sync Pro [217] to generate lip movements that matched the GAME-VHs' speech, and incorporated appropriate facial expressions. Throughout the experiment, the GAME-VHs were made to blink and vary their facial expressions and gestures, such as smiling, raising their eyebrows, waving, idle gesturing with either hand, nodding yes, and shaking their head no. Table 7.1 shows the different

Category	Speech Prompts
Social Priming, STIM-VH	STIM-VH: *"Matt won all the rounds yesterday, I'm so unlucky in this game, I only won 2 out of 10"*; GAME-VH: *"You'll get them next time"* STIM-VH: *"Hope you have better luck today"*; GAME-VH: *"thank you"*; STIM-VH: *"Oh you've got a visitor, I'll leave you two to play"* STIM-VH: *"Catch you later"*; GAME-VH: *"see you later"*
Social Priming, STIM-DOG	STIM-DOG sniffing sound; GAME-VH: *"You got it"*; STIM-DOG barking sound; GAME-VH: *"You're energetic today"*; STIM-DOG sniffing sound; GAME-VH: *"Who's a good dog'*
Social Priming, STIM-ROBOT	STIM-ROBOT: beep sound #1; GAME-VH: *"You got it"*; STIM-ROBOT: beep sound #2; GAME-VH: *"You're charged up today"*; STIM-ROBOT: beep sound #3; GAME-VH: *"Good job Robbie"*
Greeting & Game Start, GAME-VH	GAME-VH: *"Hi my name is Julie/Katie/Suzi/Stacy"*; GAME-VH: *"Nice to meet you"*; GAME-VH: *"that's my friend Remy/dog Bailey/robot Robbie"*; GAME-VH: *"how are you?"*; GAME-VH: *"I'm doing well, thank you"*; GAME-VH: *"Come on in, please have a seat"*; GAME-VH: *"I guess it's time to start"*
Game Responses, GAME-VH	GAME-VH: *"yes/yup/that's right"*;GAME-VH: *"no/nope/that's not right"*; GAME-VH: *"kind of but try again, not quite but try again, that's close but try again"*
Game End, GAME-VH	GAME-VH: *"I think you ran out of questions/I think you ran out of time"*; GAME-VH: *"Don't forget to write your last guess on the paper back there"*; GAME-VH: *"It was nice playing with you, see you later"*

Table 7.1: The speech/sound prompts voiced by different virtual

speech/audio prompts voiced by the GAME-VHs and the other stimuli. The GAME-VHs used a variety of prerecorded speech prompts for the different phases of the interaction. We recorded these speech prompts using the Audacity software [19] and the voice of a female native English-speaking research personnel from our group.

7.2.2.3.2 *Virtual Human Stimulus (*STIM-VH*)*

We acquired a 3D model of a character named Remy from Adobe Mixamo [5] and made slight adjustments. The blendshapes of the Remy character were used to control its facial expressions and lip movements while talking. Similar steps to those of the GAME-VHs (above) were taken for STIM-VH for the blinking animation and its facial expressions, gestures, and lip movements, while in this case, the voice of a male native English-speaking co-experimenter was used. Figure 7.1 at (a) shows a snapshot of the interaction between a GAME-VH and the STIM-VH character, and at (e) shows the STIM-VH at its destination position after the social priming phase was over. Table 7.1 lists the speech prompts used between the GAME-VHs and STIM-VH during the social priming phase. The STIM-VH was facing the GAME-VH throughout the social priming phase, and only looked towards the doorway where the participants were standing just before saying the phrase *"Oh you've got a visitor, I'll leave you two to play."* At that point the STIM-VH slowly looked back, stood up from its stool, walked to the stimuli destination position where his desk was placed, sat behind his computer, and looked at his computer the whole time with headphones on his ears as shown in Figure 7.1 at (e).

*7.2.2.3.3 Virtual Dog Stimulus (*STIM-DOG*)*

We purchased a 3D rigged and animated model of a golden retriever dog from the Unity asset store [211]. We chose a golden retriever dog model as real-life examples of this breed were previously used in social catalyst studies with real dogs and real humans (see Sec. 2.1.2). Blinking animations were added to the STIM-DOG model. Figure 7.1 at (b) shows a snapshot of the interaction between the GAME-VH and the STIM-DOG character, and at (f) the STIM-DOG at its destination position after the social priming phase was over. Table 7.1 lists the speech prompts used between the GAME-VHs and STIM-DOGduring the social priming phase. During this phase, the STIM-DOG faced the GAME-VH and wagged its tail while transitioning between three animations of four-legged idle, sniffing and scratching the ground, and playfully crouching while barking. At the end of the social priming phase, the STIM-DOG turned its head and looked at the doorway, where the participant was standing, turned back towards the GAME-VH, stopped wagging its tail, and moved towards the stimuli destination position and idly lay on the floor as shown in Figure 7.1 at (f).

*7.2.2.3.4 Virtual Robot Stimulus (*STIM-ROBOT*)*

We acquired a 3D rigged and animated model of a virtual robot from the Unity Asset Store [210] and made slight adjustments. Figure 7.1 at (c) shows a snapshot of the interaction between the GAME-VH and the STIM-ROBOT character, and at (g) shows the STIM-ROBOT at its destination position after the social priming phase was over. We chose to avoid a human-like or animal-like robot appearance as we did not want our participants to perceive the STIM-ROBOT as a robotic version of a human or a dog, and to potentially look for animal-like or human-like qualities in the robot. We used a rolling animation for the STIM-ROBOT's movements, slight playful motions around the yaw axis, and blinking for the eyes. We removed the three legs of the 3D model and adjusted it to roll from one place to the next, as during our internal pilot testing we found that the robot's movements with its legs could make it seem aggressive or unsafe. Our choice for STIM-ROBOT's appearance was informed by the interactive mobile robots that have been on the market [220], such as Cozmo [75] and Sphero [240]. Also, this robot was closer to a form factor, such as the Qin robot [50] that was rated very highly on the warmth dimension [212]. STIM-ROBOT made short beep sounds during the game play as shown in Table 7.1. The beep sounds were acquired from Zapsplat [275]. During the social priming phase, STIM-ROBOT slowly motioned around its yaw axis, mostly facing the VH with its eyes indicating a happy emotion as shown in Figure 7.1 at (c). Before the end of the social priming phase, the robot rotated around to look back at the doorway, where the participants were standing, then rotated back towards the GAME-VH with its eyes transitioning to normal mode and rolled towards the stimuli destination position in the corner of the room as shown in Figure 7.1 at (g).

7.2.2.4 *Hypotheses*

Inspired by the positive influences of social priming and backstory on perceptions of virtual humans [33, 68–70], the potential of real dogs in creating a positive image of the real human dog owners based on Halo Effect and Social Catalyst literature [107, 169, 218, 266], and the potential benefits of interactions with social robots [87, 136, 140], we present the following hypotheses:

- **H1:** social priming facilitated by another VH compared to non-social priming enhances participants' social interaction with the VH (i.e., increased social presence) and results in a more positive perception of the VH (i.e., enhanced Affective Attraction, Inclination, and Inclusion of Other in the Self).
- **H2:** The above benefits of social priming are not limited to humanoid entities and can be induced by non-humanoid entities.
- **H3:** The presence of social priming stimuli will influence participants' attention behavior during the social priming phase.

7.2.2.5 *Measures*

This section presents all of our subjective and objective measures and our post-study interview questions used to assess participants' perceptions of the social priming and non-social priming conditions.

Objective Measures

- **Head Gaze:** We used a ray originating from the center of the HMD (i.e., user's face) to measure how often participants' heads were oriented towards the different GAME-VHs or other virtual stimuli depending on the condition during Stage 2 as shown in Figure7.2 at (b), and before the start of the game as an objective measure of our participants' attention.

Subjective Measures

- **Social Presence:** We used the 9-item social presence questionnaire utilized by Oh et al. [195] as an adaptation of the networked minds social presence questionnaire [34]. This questionnaire was to used to assess how together participants feel with the different GAME-VHs on a 7-point scale (1 = strongly disagree, 7 = strongly agree). Following previous work [195], we computed an aggregated score for each condition.
- **Affective Attraction:** We used the 5-item affective attraction questionnaire devised by Herbst et al. [105] to evaluate participants' perceptions of the GAME-VHs regarding the 5 factors of unpleasant/pleasant, cold/warm, positive/negative, friendly/unfriendly, and distant/close presented to participants on a 7-point scale (e.g., 1 = unpleasant, 7 = pleasant). Following previous work [105], we reversed the negative items and calculated and aggregated score for each condition.
- **Inclination:** We devised the question "How inclined do you feel to interact with your game partner more in the future?" to assess participants' inclination for future interactions based on the different conditions.
- **Inclusion of Other in the Self:** We used the single-item pictorial inclusion of other in the self (IOS) by Aron et al. [15], to assess how at one participants feel with the GAME-VHs.

Post-Study Interview

At the end of the study, aligned with our research questions (see Sec. 7.1) we conducted a semi-structured interview and asked our participants to describe their experience including their thoughts and feelings while they were waiting at the doorway, how they felt during the game, and how they divided their attention in the social priming conditions where there was another stimulus in the room with them.

7.2.2.6 Data Analysis

We adopted a mixed-methods approach for the analysis of our quantitative and qualitative data. Two participants were removed from the analysis for technical issues. We used repeated measures ANOVA at the 5% significance level for the analysis of our objective and subjective quantitative data. This decision is aligned with recent findings in the domain of statistics suggesting the robustness of parametric methods for subjective scale data [180, 185]. T-tests were utilizied for pairwise comparisons with False Discovery Rate (FDR) Correction to correct for family-wise error. After correction we adopted SPSS's approach of reporting the corrected p-values. Degrees of freedom were corrected using Greenhouse-Geisser and Huynh-Feldt estimates following a significant Mauchly's test of sphericity.

For the analysis of our participant's post-study interview responses we adopted Braun and Clarke's thematic analysis approach [44], conducted by the first author of this manuscript. The thematic analysis started with the transcription of the post-study interview audio files, followed by multiple rounds of reading the transcriptions to get familiarized with the data. Next, the data was iteratively coded and through multiple revisions grouped into themes. Table 7.2 presents our code book devised for our qualitative analysis.

Themes	Code: Definition
Social Priming vs. Non-Social Priming (54%)	**Positive Feelings**: comparing the social priming and non-social priming conditions in relation to one's feeling (e.g., feeling pleasant or demotivated) **Attention Curiosity:** talking about the positive influences of the stimuli in garnering positive curiosity **Screensaver:** talking about the use of stimuli as a screensaver while thinking/talking
Unexpectedness Benefits (45%)	**Normalcy:** Using words such as normal, natural, authentic, common, expected, realistic or their opposites to describe the general pre-game interactions and/or the presence of the different stimuli **Real-Life Comparison:** Talking about the conditions in relation to real-life experiences **Previous Technology Comparison:** Talking about the conditions in relation to past technological exposures
Variation Benefits (31%)	**Apprehension:** describing feelings of anxiety with VHs based on anxiety with real human strangers **Positive Feelings:** describing preference for the non-human stimuli

Table 7.2: Thematic Analysis Codebook.

7.3 Results

This section presents our quantitative (subjective and objective) results and the three themes that emerged from the qualitative analysis of our participants' post-study interview responses. Table 7.3 summarizes our quantitative results.

Measure	Main Effect	Pair-Wise Comparison with FDR
Head Gaze at Stimuli	$F(2,42) = 5.84$, $\boldsymbol{p = 0.006}$, $\eta_p^2 = 0.22$	STIM-DOG vs. STIM-ROBOT: $t(21) = 4.29$, $\boldsymbol{p < 0.001}$, $d = 0.92$ STIM-DOG vs. STIM-VH: $t(21) = 1.95$, $p = 0.096$, $d = 0.42$
Head Gaze at GAME-VH	$F(3,63) = 44.52$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.68$	STIM-DOG vs. STIM-PHONE: $t(21) = -8.97$, $\boldsymbol{p < 0.001}$, $d = -1.91$ STIM-ROBOT vs. STIM-PHONE: $t(21) = 6.41$, $\boldsymbol{p < 0.001}$, $d = -1.37$ STIM-VH vs. STIM-PHONE: $t(21) = -11.36$, $\boldsymbol{p < 0.001}$, $d = -2.42$
Social Presence (0.91)	$F(2.22, 46.52) = 0.89$, $p = 0.427$, $\eta_p^2 = 0.041$	—
Affective Attraction (0.84)	$F(3,63) = 4.72$, $\boldsymbol{p = 0.005}$, $\eta_p^2 = 0.18$	STIM-DOG vs. STIM-PHONE: $t(21) = 3.06$, $\boldsymbol{p = 0.018}$, $d = 0.65$ STIM-ROBOT vs. STIM-PHONE: $t(21) = 2.29$, $p = 0.066$, $d = 0.49$ STIM-VH vs. STIM-PHONE: $t(21) = 3.23$, $\boldsymbol{p = 0.018}$, $d = 0.69$
Inclination	$F(3,63) = 6.15$, $\boldsymbol{p < 0.001}$, $\eta_p^2 = 0.23$	STIM-DOG vs. STIM-PHONE: $t(21) = 3.24$, $\boldsymbol{p = 0.012}$, $d = 0.69$ STIM-ROBOT vs. STIM-PHONE: $t(21) = 2.83$, $\boldsymbol{p = 0.02}$, $d = 0.60$ STIM-VH vs. STIM-PHONE: $t(21) = 5.374$, $\boldsymbol{p < 0.001}$, $d = 1.15$
Inclusion of Other in the Self	$F(3,63) = 3.18$, $\boldsymbol{p = 0.030}$, $\eta_p^2 = 0.13$	STIM-DOG vs. STIM-PHONE: $t(21) = 2.54$, $p = 0.075$, $d = 0.54$ STIM-DOG vs. STIM-ROBOT: $t(21) = 2.41$, $p = 0.075$, $d = 0.51$

Table 7.3: Summary of all of the subjective/objective quantitative results. Cronbach α values are presented in parentheses.

7.3.1 Objective Measures

This section presents the results of our objective measures summarized in Table 7.3.

7.3.1.1 Head Gaze at Stimuli:

Figure 7.3 at (a) shows the results for the Head Gaze at Stimuli measure. A significant difference in pair-wise comparisons indicate that participants' head gaze was directed towards the dog more often than the robot ($\boldsymbol{p} = \boldsymbol{0.002}$).

7.3.1.2 Head Gaze at GAME-VH*:*

Figure 7.3 at (b) illustrates the results for the Head Gaze at GAME-VH measure. Significant differences in pair-wise comparisons indicate that participants' Head Gaze were directed at the GAME-VH less often when another stimuli was present in the room ($\boldsymbol{p} < \boldsymbol{0.001}$).

7.3.2 Subjective Measures

This section presents the results of our subjective measures summarized in Table 7.3.

7.3.2.1 Social Presence:

Figure 7.3 at (c) indicates participants' level of social presence experienced with the different GAME-VHs. We did not find a significant main effect of condition on the level of social presence experienced with the GAME-VHs. Considering also the magnitudes and variance, social priming may have had no effect on how present participants felt with the different GAME-VHs.

7.3.2.2 *Affective Attraction:*

Figure 7.3 at (d) shows the level of affective attraction experienced towards the different GAME-VHs for each condition. Significant differences in pair-wise comparisons indicate that the two STIM-VH and STIM-DOG conditions positively influenced participants' levels of affective attraction towards the GAME-VHs in comparison to the STIM-PHONE condition ($p < 0.05$).

7.3.2.3 *Inclination:*

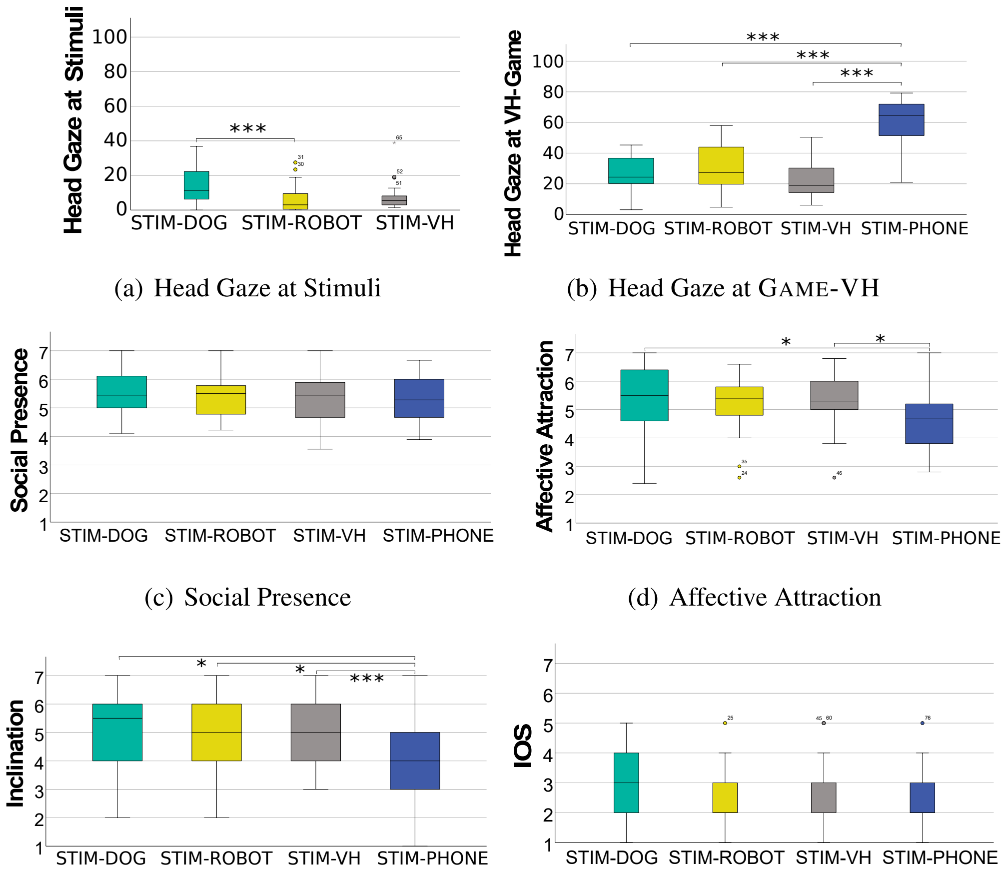
Figure 7.3 at (e) shows the differences between participants' inclination scores. Significant differences in pair-wise comparisons indicate participants were more inclined to interact with the GAME-VHs in all of the social priming conditions compared to the STIM-PHONE condition ($p < 0.05$).

7.3.2.4 *Inclusion of Other in the Self:*

Figure 7.3 at (f) shows the results for this measure. We only found trends in the pairwise comparisons, cautiously suggesting that participants may have felt more at one with the GAME-VHs with the virtual dog compared to the STIM-ROBOT and STIM-PHONE conditions.

7.3.3 *Qualitative Results*

This section presents the three themes that emerged from the qualitative analysis of our participants' post-study interview responses. For each theme, the total number of opinions presented for each condition can exceed the number of participants as each of them may have multiple opinions for each condition for a given theme.



(a) Head Gaze at Stimuli
(b) Head Gaze at GAME-VH
(c) Social Presence
(d) Affective Attraction
(e) Inclination
(f) Inclusion of Other in the Self

Figure 7.3: Objective and subjective results (higher is better): (a) Head Gaze at Stimuli, (b) Head Gaze at GAME-VH, (c) Social Presence, (d) Affective Attraction, (e) Inclination, (f) Inclusion of Other in the Self. Statistical significance: *** ($p<0.001$), ** ($p<0.01$), * ($p<0.05$).

7.3.3.1 Social Priming Enhanced User's Experience Compared to Non-Social Priming:

Twelve of our participants (54%) described at least one positive benefit of the social priming conditions compared to the non-social priming condition.

For nine participants (41%), these positive benefits were more explicit as they found the social priming conditions to be more welcoming, pleasant, and contextual. The social priming conditions being perceived as more welcoming is especially interesting, as all the GAME-VHs had the same speech prompts, gestures, and facial expressions for welcoming the participants for each condition. On the other hand the non-social priming condition was described as unpleasant and demotivating. Overall, 12 positive mentions were recorded for the STIM-DOG condition followed by 10 positive mentions each for the STIM-VH and STIM-ROBOT conditions.

> *P15: "...last condition was very distant...they were looking at their phone and they did not realize that somebody is at the door first two conditions were really good because they were interacting with their in the first case robot and in the second case their pet but as soon as they realized they greeted and they wanted to welcome in and even the third condition I would say it was still pleasant because they were giving 100% of their attention to the person they were talking to..."*

Six participants (27%) noted that at least one of the social priming conditions garnered a positive sense of curiosity as they would glance at them to see what they would do next or get clues for the game. Three participants (13%) appreciated the presence of the stimuli during the game as they used them as screen savers while they were thinking/talking to the GAME-VHs, mentioning that they commonly look around and focus on other things when talking/thinking.

> *P12: "...as I was talking and asking questions I kind of like used as a screen saver...I would look over to it [social priming stimuli] to give my mind a second thing to think about so it felt like some progress was being made..."*

7.3.3.2 Unexpected Social Priming Can Have Positive Benefits:

Ten of our participants (45%) assessed the social and non-social priming interactions based on how closely it resembled their real-life experiences or their previous exposures to similar technology. Among this group, the STIM-VH condition was regarded as the most common and normal compared to the other conditions (six participants, 27%), followed by the STIM-PHONE (four participants, 18%), and the VH-Dog (two participants, 9%).

> *P15: "...the one with the dog I felt the most comfortable with cause it seemed more authentic and the one where she was talking with that guy, just cause it seemed like real like situations that could happen...I felt like a little more like curious I guess [with] the robot one, but also it feels a bit more like not actually real because we don't have anything like that in real life...the one when she was on her phone...that felt authentic to me because that sometimes happens, you gotta have to wait for someone to notice you when you are standing at the door..."*

Interestingly, although being common and normal was deemed as a positive quality for the above conditions, the opposite very rarely led to a negative experience. Eight participants in the STIM-ROBOT condition (36%) and six (27%) participants in the STIM-DOG condition did not find the social priming interactions in these conditions as common or expected. However, the unexpectedness resulted in an added sense of positive curiosity and amusement for most, with only two participants (9%) deeming the uncommonness of the STIM-DOG and STIM-ROBOT conditions as negative and weird.

> *P5: "...I felt that it was kind of cool that there was a dog there with the robot as well...I just thought they are more interesting because most AR avatars aren't dogs or robots..."*

7.3.3.3 Adding Variation to Social Priming Stimuli Can be Beneficial:

The experience of seven of our participants (31%) was influenced by the presence or absence of non-human stimuli. In this group, three participants (13%) described their general feelings of anxiety and apprehension when interacting with strangers, which was brought to the fore when presented with the STIM-VH and STIM-PHONE conditions. The remaining four participants (18%) noted feeling more social, happier, and comfortable in the STIM-DOG and/or STIM-ROBOT conditions due to liking dogs and the added curiosity and excitement brought about by these stimuli.

> *P20: "...with the robot I was curious cause I wasn't expecting to see a robot so I was more invested...in the dog too I don't have a dog but I like dogs I trust them...with the other person I get anxious around people so I wasn't as inclined to like having the other person there it almost felt like I was interrupting I guess since they already were in the middle of something cause I don't feel like I'm interrupting a dog but when it's a person-person interaction I was like oh maybe I'm interrupting something here and then when they were on their phone was probably the worst cause you just had to stand there and I guess I'm bothering her I felt bad like oh she's on her phone oh my bad..."*

7.4 Discussion

Our quantitative and qualitative findings show the promise of social priming to both positively influence participants' perceptions of the GAME-VHs compared to the non-social priming, and to impact how participants divide their attention. Also, we found that some of the benefits of social priming can be induced by non-humanoid entities. However, we did not find any evidence for social priming enhancing the quality of social interaction between the participants and the GAME-VHs. Here we provide a detailed discussion of the findings.

7.4.1 Potential Dual Benefits of Social Priming

Our quantitative and qualitative results suggest that social priming may have dual benefits: (a) enhancing participants' perceptions of the GAME-VHs, and (b) enhancing participants' user experience.

Regarding point (a), we found that participants attributed more positive affective characteristics to the GAME-VHs in the STIM-VH and STIM-DOG conditions, such as finding the GAME-VHs more warm and friendly than the non-social priming condition (trend for STIM-ROBOT). Also, participants felt more inclined to engage in future interactions with the GAME-VHs in all social priming conditions than the non-social priming condition. These findings also reveal that social priming can be facilitated with non-humanoid entities, with similar differences for the STIM-DOG and STIM-ROBOT conditions (trend for affective attraction in the STIM-ROBOT condition). These findings correspond to previous research on real dogs creating a halo effect for their owners [30, 98, 169, 266, 270]. We speculate that the positive findings for the virtual robot may be related to participants' positive curiosity and excitement resulting from its presence. These findings partially support **H1** and **H2**. This partial support is due to the fact that unlike previous work [68–70], we did not find higher Social Presence scores in the social priming conditions compared to the non-social priming condition, with relatively high Social Presence scores across all conditions, as shown in Figure 7.3 at (c). This finding may be explained by the fact that most of our participants mentioned being engaged in the game and finding the mechanics of the social interactions with the GAME-VHs to be similar across all conditions, leading to similar social presence scores. Interestingly, a few of our participants noted that seeing a VH on their phone seemed normal to them, which may explain the unaffected social presence scores.

Also, previous research looking at dyadic social interactions has found that using one's phone continuously during the social interaction negatively influences the other person's perceptions [4, 59, 94]. Although our STIM-PHONE condition did not include such a scenario—continuous phone usage during the interaction—some of our participants found it less pleasant compared to the social priming condition. Based on our participants' qualitative feedback, we speculate that the negative perceptions in the STIM-PHONE condition is more associated with the participants' perception of having to wait longer at the doorway, while this point was not mentioned for any of the other conditions.

As expected, our participants paid more attention to the GAME-VHs in the non-social priming condition as no other stimuli was present in the room, supporting our hypothesis **H3** that participants divided their attention between the GAME-VHs and the different social priming stimuli in the social priming conditions. Separately, in response to **RQ1** and **RQ2**, our participants paid more attention to the virtual dog than the virtual robot at the beginning of the interaction—similar, but a trend was observed between STIM-DOG and STIM-VH conditions. This may be due to the virtual dog having the right levels of being perceived as pleasant and unexpected compared to the other stimuli. For instance, although only a trend, participants seemed to feel more at one with the GAME-VHs in the STIM-DOG condition compared to STIM-ROBOT and STIM-PHONE (see IOS in Table 7.3).

In response to **RQ1** and **RQ2**, we also found the influence of social priming on participants' overall experience captured in point (b) noted above. Our qualitative findings suggest that some of our participants found the social priming phase as a pleasant and interesting interaction to observe, adding to their sense of curiosity with some participants finding the virtual dog and the virtual robot to be unexpected in a positive way. Based on these findings, we see benefits for giving context to interactions with VHs through social priming and exploring varying stimuli since interactions with virtual dogs or robots can provide novel background information about the VHs, their personality, and affective states that may facilitate longer-term engagement. For instance, VHs that share first-person perspective background information are found to be more engaging in the long run [33].

7.4.2 Limitations

Since the ray originating from the center of participants' heads would miss both the GAME-VH and the different social priming stimuli when participants tried to fit both entities in the field of view of the HMD, the Head Gaze measures cannot entirely capture our participants' focus of attention. We plan to utilize eye tracking in future studies to more precisely pinpoint the differences in participants' division of attention.

Also, all GAME-VHs were involved in relatively positive interactions during the social priming phase, and future studies should explore the influence of more neutral interaction content. That said, except one participant, all attributed the influences of the social priming to the general interaction between the GAME-VHs and the different stimuli and not to the specific content of the interaction.

Lastly, as we were interested in the influence of the social interactions facilitated by various social priming stimuli, we did not study the mere presence of each social stimuli; hence, future work is needed to determine the influence of the social exchange vs. the mere presence of a social stimuli (e.g., a virtual dog socially interacting with a virtual human vs. a virtual dog just present next to the virtual human).

7.5 Conclusion

In this chapter, we presented a human-subjects user study to assess the potential of social priming through social interactions between different VH and virtual stimuli, which included another VH, a virtual pet dog, a virtual personal robot and compared it to a non-social priming condition. We found that social priming leads to a more positive perception of VHs than the non-social priming condition; however, participants experienced similar levels of social presence in all conditions.

Additionally, our findings point towards benefits in adding variation to social-priming stimuli. For instance, some of our participants were positively surprised by the presence of the virtual dog and the virtual robot and a few experienced social anxiety with the VH stimuli.

CHAPTER 8: CONCLUSIONS AND FUTURE WORK

In this dissertation, in light of the positive benefits of HDI [30, 267] and the limitations faced by some individuals to benefit from such interactions [96, 100, 167, 200, 264], I studied the social and behavioral influences of interactions with virtual dogs as embodied agents in AR/VR.

As noted in Section 1.4, this dissertation contributes to the broader domain of embodied agents in AR/VR in the following ways. First, I identified a scope for human-virtual dog interaction research, to allow for a systematic investigation of virtual dogs as embodied agents. The research scope reflects the convergence of what I call Human Effects and Research Considerations. To arrive at the Human Effects category, I reviewed previous work on HDI and identified and presented the similarities captured in previous work, especially previous systematic literature reviews. To arrive at the Research Considerations, I conducted a systematic literature review on embodied agents in AR HMD-based environments from 2000-2020 and identified five primary research areas that had received considerable attention in the past 20 years [189].

Second, within this research scope, inspired by the potential of virtual dogs in companionship roles and motivated by fundamental open research questions in the Human-Virtual Dog Interaction research scope, I conducted four human-subject experiments. These experiments go beyond just the immediate interaction between the real human user and the virtual dog as a whole and present an expanded analysis on the influence of virtual dogs' presence and behavior in shared spaces investigating more complex social dynamics with other real and virtual humans. Through these experiments, I identified: (a) virtual dogs' simulated responsiveness leads to a higher degree of copresence in human participants and enhances their quality of experience, (b) their potential as comforting entities when assuming the role of social support figures, (c) their effectiveness when used as attention guidance mechanisms while enhancing participants' quality of experience, and

(d) their ability to influence participants' perceptions of other real/virtual humans depending on the connotation of the virtual dog's interaction with that other real/virtual human.

8.1 Summary

Here, I will summarize the relationship between the thesis statements (see Section 1.3 and the findings of the four experiments presented in previous chapters:

- **TS1:** As discussed in Chapter 4, Chapter 5, and Chapter 6, I found that interactions with virtual dogs who behave similarly to real dogs result in subjective and behavioral changes that align with HDI literature findings. In Chapter 4, I found that while in the presence of another real human, walking a virtual dog in AR changed participants' proxemics behavior than walking without a virtual dog, with participants allocating more physical space for the virtual dog. In Chapter 5, I found that participants perceived the virtual dog to be an effective support figure as participants expressed feeling more relaxed in its presence. In Chapter 6, I found that using a virtual dog as an attention guidance mechanism in a 360 virtual experience enhanced participants' user experience, such as lower levels of fear of missing out and distraction while feeling more encouraged to explore without feeling rushed compared to no guidance and graphical arrow attention guidance mechanism.
- **TS2:** As discussed in Chapter 7, I found that using a virtual dog as a social priming stimulus, where participants observe a virtual human interacting with her virtual pet dog, enhances their perceptions of the virtual human such as finding the virtual human more friendly and feeling more inclined to interact with it in the future compared to a non-social priming condition.
- **TS3:** As discussed in Chapter 4 and Chapter 6, I found that simulated responsiveness of

the virtual dog towards the participants and other entities in the physical/virtual environment led to higher levels of copresence with the virtual dog and enhanced participants' user experience compared to a virtual dog lacking such simulated responsiveness. In Chapter 4, the simulated responsiveness of the virtual dog took the form of it being affected (i.e., getting hurt and falling over) as a result of a real human walking through it. Observation of this event led to our participants feeling more together with their virtual dogs. In Chapter 6, the simulated responsiveness of the virtual dog took the form of it acknowledging the presence of the participants in the virtual environment and specific events that were happening within that environment. Such acknowledging behaviors led our participants to experience higher degrees of place and plausibility illusion and preferring to use such a mechanism for attention guidance purposes in 360 virtual experiences.

- **TS4:** As discussed in Chapter 4, I found that simulated responsiveness of the virtual dog towards real human bystanders in the physical environment influences participants' perceptions of those real humans. As mentioned earlier, in this Chapter, the simulated responsiveness of the virtual dog took the form of it being affected (i.e., getting hurt and falling over) as a result of a real human walking through it compared to observations of their virtual dog lacking such simulated responsiveness. Observation of this event led to our participants associating less positive affective attributes to the real human bystanders, such as finding them less friendly and more distant.

8.2 Limitations

Considering the novelty of researching virtual animals and dogs and the potential of using AR/VR technology to realize virtual dogs that can be spatially present in users' physical and virtual environments, in this dissertation, I utilized controlled laboratory studies with AR/VR technology to provide support for my thesis statements (see Section 1.3). Such controlled experiments can inherently introduce certain limitations.

The participant population of the four studies lacked diversity regarding factors such as gender, race, ethnicity, and socioeconomic status. Thus, larger and more diverse target populations can present a more comprehensive and accurate image of the variety of influences that virtual dogs can have on humans and better inform the utilization of virtual dogs for applications such as therapy.

Additionally, although the positive benefits of interactions with real dogs and the limitations faced by many to benefit from these interactions has been one of my main motivations to study virtual dogs, I did not test any of the virtual dogs within the bounds of this dissertation prototypes with such populations. This decision was mainly due to the novelty of the human-virtual dog (and animal) interaction field and the need to better understand the virtual dog itself as an entity before utilizing it in an applied context. Thus, specifically, it is important to research the influence of virtual dogs and other virtual animals with populations that can benefit from animal-assisted activities but cannot be involved in such activities. Also, in two of the four studies, I explicitly recruited participants who are open to interactions with real dogs and do not have a phobia of real dogs. I made this decision inspired by previous HDI literature and motivated by the fact that individuals with phobias or those who dislike real dogs may not be receptive to interactions with virtual dogs. That said, it would be interesting to explore the influence of virtual dogs by accounting for participants' individual differences, such as those who may not like dogs.

Also, although our participants' responses to interactions with virtual dogs have been positive in general and compared to other realizations of embodied IVAs, it is important to note that all these interactions were relatively short-term. Thus, it may be the case that human users may have different perceptions and thus form different expectations when virtual dogs can adopt a more pervasive role in users' daily lives, across devices (handheld, HMD, TV, etc.), and modalities (visual, voice, etc.). On a positive note, the increasing popularity of AR/VR technology is promising as it can provide opportunities for more long-term, in the wild studies with more diverse populations.

Last, all of our studies presented participants with novel experiences using AR/VR technology and included interactions with virtual dogs that are much less common than interactions with virtual humans. These choices may have inadvertently influenced participants' perceptions through novelty effects [243] and demand characteristics [198]. Although I utilized interviews to gauge whether my participants' responses resulted from such influences, conducting field studies with more diverse participants in a more longitudinal format will allow for a more accurate representation of users' quality of experience.

8.3 Future Work

The Human-Virtual Dog Interaction research scope identified in this dissertation (see Section 1.2) presented many open research questions for the investigation of virtual dogs and animals.

One interesting area for future work is understanding the role of virtual dogs' appearance and behavioral fidelity, compared to a real dog, regarding the potential influences they can have on human users while utilized in different applications. For instance, in three of the four experiments in this dissertation, with technological limitations in mind, I utilized 3D virtual dog models that have relatively low-fidelity appearances and relatively high-fidelity behaviors compared to a real dog. And yet, many of my study participants noted that the virtual dog reminded them of real dogs in these studies. By systematically varying different appearance and behavioral fidelity levels compared to real dogs, future studies can investigate which attribute (behavior or appearance) is the leading source of the virtual dog's influence. I speculate that this investigation can lead to varying findings when the virtual dog assumes significantly different roles. For instance, if a virtual dog is used to guide rescuers based on findings obtained from a real aerial vehicle (drone) in a search and rescue scenario, both high-fidelity appearance and behavior seem important for real human users to trust the information communicated by the virtual dog. On the other hand, if a virtual dog is assuming the role of a companion, it may be the case that users may like to largely personalize their virtual dog companions on both dimensions of appearance and behavior inspired by previous pets or favorite cartoon characters. Specifically, focusing on anthropomorphic virtual animals, similar to many cartoon characters, it would be interesting to explore whether the added anthropomorphism influences how humans perceive virtual animals in terms of qualities, such as evaluative nature and intelligence.

Another valuable future research direction is the adoption of methods such as stimulus sampling [110] that can allow for more generalizability when it comes to the potential influences of virtual dogs in general and compared to other types of stimuli. For example, in my studies, I only utilized two breeds of virtual dogs, a Beagle and a Golden Retriever; however, with stimulus sampling, it would be possible to test different breeds of virtual dogs that can result in more generalizable findings.

Last, compared to real and robotic dogs, virtual dogs realized using current technology lack the tactile and haptic feedback that can allow for more natural interactions with the virtual dogs, such as petting the dog. That said, exploring realistic virtual dog behaviors that correspond closely to users' behaviors (e.g., a user petting a virtual dog) presents novel opportunities to explore the influence of behavioral realism in light of no haptic feedback. With the sense of touch identified as one of the factors reducing humans' stress during interactions with real dogs, such as petting the real dog [233, 257], it is valuable to investigate the influence of virtual dogs' simulated responsiveness to user's touch on user's stress levels and inclination for future interactions, such as the virtual dog moving its body synchronized with the user's petting motion in the absence of haptic and tactile feedback.

APPENDIX A: IRB APPROVAL LETTERS

A.1 Letter 1

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

January 31, 2019

Dear Nahal Norouzi:

On 1/31/2019, the IRB reviewed the following submission:

Type of Review:	Modification and Continuing Review
Title:	Perception of Virtual Animals in Augmented Reality
Investigator:	Nahal Norouzi
IRB ID:	MODCR00000019
Funding:	Name: Office of Naval Research, Grant Office ID: ONR award# N00014-17-1-2927; Name: National Science Foundation (NSF), Grant Office ID: NSF award# 1800961
Documents Reviewed:	• Protocol, Category: IRB Protocol; • Basdogan Copresence, Category: Recruitment Materials; • Basic empathy scale, Category: Recruitment Materials; • big five personality test 1, Category: Recruitment Materials; • big five personality test 2, Category: Recruitment Materials; • Comfort from companion animal, Category: Recruitment Materials; • demographics, Category: Recruitment Materials; • familiarity with technology, Category: Recruitment Materials; • flyer, Category: Recruitment Materials; • interaction related questionnaire, Category: Recruitment Materials; • interpersonal reactivity index, Category: Recruitment Materials; • Levenson psychopathy scale, Category: Recruitment Materials; • Lexington attachment to pet scale, Category: Recruitment Materials; • Moral identity, Category: Recruitment Materials; • multi dimensional emotional empathy scale,

Page 1 of 3

	Category: Recruitment Materials; • GregWelch2.pdf, Category: Training; • JasonHochreiter2.pdf, Category: Training; • NASA TLX, Category: Recruitment Materials; • petAttachmentQuestionnaire, Category: Recruitment Materials; • PetAttitudeScale, Category: Recruitment Materials; • Presence Questionnaire, Category: Recruitment Materials; • ConsentForm, Category: Consent Form; • Participant Procedure, Category: Recruitment Materials; • qualitative questionnaires, Category: Recruitment Materials; • quantitative questionnaires, Category: Recruitment Materials; • social presence questionnaire, Category: Recruitment Materials; • simulator sickness questionnaire, Category: Recruitment Materials; • system usability scale, Category: Recruitment Materials; • user experience questionnaire, Category: Recruitment Materials; • Faculty Advisor Review, Category: Faculty Research Approval; • AlexisLambert1.pdf, Category: Training; • AlexisLambert2.pdf, Category: Training; • AustinErickson1.pdf, Category: Training; • AustinErickson2.pdf, Category: Training; • GerdBruder1.pdf, Category: Training; • GerdBruder2.pdf, Category: Training; • GregWelch1.pdf, Category: Training; • JasonHochreiter1.pdf, Category: Training; • JonathanJules1.pdf, Category: Training; • JonathanJules2.pdf, Category: Training; • KangsooKim1.pdf, Category: Training; • KangsooKim2.pdf, Category: Training; • MyunghoLee1.pdf, Category: Training; • MyunghoLee2.pdf, Category: Training; • NahalNorouzi1.pdf, Category: Training; • NahalNorouzi2.pdf, Category: Training; • RyanSchubert1.pdf, Category: Training; • RyanSchubert2.pdf, Category: Training; • SalamDaher1.pdf, Category: Training; • SalamDaher2.pdf, Category: Training;

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

The IRB approved the protocol from 1/31/2019 to 1/30/2020.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Adrienne Showman
Designated Reviewer

A.2 Letter 2

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

February 11, 2019

Dear Nahal Norouzi:

On 2/11/2019, the IRB reviewed the following submission:

Type of Review:	Modification
Title:	Perception of Virtual Animals in Augmented Reality
Investigator:	Nahal Norouzi
IRB ID:	MOD00000071
Funding:	Name: Office of Naval Research; Name: National Science Foundation (NSF)
Grant ID:	ONR award# N00014-17-1-2927, NSF award# 1800961
Documents Reviewed:	• Protocol, Category: IRB Protocol; • ConsentForm, Category: Consent Form; • demographics, Category: Recruitment Materials; • Interpersonal Attraction Scale, Category: Recruitment Materials; • participant procedure, Category: Recruitment Materials; • Debriefing Statement, Category: Recruitment Materials; • interaction related questionnaire, Category: Recruitment Materials; • Command List, Category: Recruitment Materials;

The IRB approved the protocol from 2/11/2019 to 1/30/2020.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Page 1 of 2

Adrienne Showman
Designated Reviewer

A.3 Letter 3

UCF

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

February 21, 2019

Dear Nahal Norouzi:

On 2/21/2019, the IRB reviewed the following submission:

Type of Review:	Modification
Title:	Perception of Virtual Animals in Augmented Reality
Investigator:	Nahal Norouzi
IRB ID:	MOD00000087
Funding:	Name: Office of Naval Research, Grant Office ID: ONR award# N00014-17-1-2927; Name: National Science Foundation (NSF), Grant Office ID: NSF award# 1800961
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• Protocol, Category: IRB Protocol; • Affective Attraction Questionnaire, Category: Recruitment Materials; • Godspeed Questionnaire, Category: Recruitment Materials; • Post Questionnaire, Category: Recruitment Materials;

The IRB approved the protocol from 2/21/2019 to 1/30/2020.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Page 1 of 2

Adrienne Showman
Designated Reviewer

A.4 Letter 4

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

January 10, 2020

Dear Nahal Norouzi:

On 1/10/2020, the IRB reviewed the following submission:

Type of Review:	Modification and Continuing Review
Title:	Perception of Virtual Animals in Augmented Reality
Investigator:	Nahal Norouzi
IRB ID:	MODCR00000340
Funding:	Name: Ofc of Naval Research, Grant Office ID: ONR award# N00014-17-1-2927; Name: Natl Science Fdn (NSF), Grant Office ID: NSF award# 1800961
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• ConsentForm, Category: Consent Form; • Debriefing Statement, Category: Consent Form;

The IRB approved the protocol from 1/10/2020 to 1/9/2021.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Adrienne Showman
Designated Reviewer

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A.5 Letter 5

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

December 1, 2020

Dear Nahal Norouzi:

On 12/1/2020, the IRB reviewed the following submission:

Type of Review:	Modification and Continuing Review
Title:	Perception of Virtual Animals in Augmented Reality
Investigator:	Nahal Norouzi
IRB ID:	MODCR00000425
Funding:	Name: Ofc of Naval Research, Grant Office ID: ONR award# N00014-17-1-2927; Name: Natl Science Fdn (NSF), Grant Office ID: NSF award# 1800961
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• ConsentForm, Category: Consent Form; • Debriefing Statement, Category: Consent Form;

The IRB approved the protocol from 12/1/2020 to 11/30/2021.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. Guidance on submitting Modifications and a Continuing Review or Administrative Check-in are detailed in the manual. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Gillian Bernal
Designated Reviewer

A.6 Letter 6

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

UNIVERSITY OF CENTRAL FLORIDA

APPROVAL

October 16, 2019

Dear Nahal Norouzi:

On 10/16/2019, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title:	Perception of Virtual Animals in Augmented Reality as Social Support Figures
Investigator:	Nahal Norouzi
IRB ID:	STUDY00000955
Funding:	Name: National Science Foundation (NSF), Grant Office ID: NSF award# 1800961; Name: Office of Naval Research, Grant Office ID: ONR award# N00014-17-1-2927
Grant ID:	NSF award# 1800961; ONR award# N00014-17-1-2927;
IND, IDE, or HDE:	None
Documents Reviewed:	• Basic Empathy Scale.pdf, Category: Survey / Questionnaire; • BigFivePersonalityTest.pdf, Category: Survey / Questionnaire; • BigFivePersonalityTest2.pdf, Category: Survey / Questionnaire; • ComfortFromCompanionAnimal.pdf, Category: Survey / Questionnaire; • Copresence Basdogan.docx, Category: Survey / Questionnaire; • Demographic.docx, Category: Survey / Questionnaire; • FamiliarityWithTechnology.docx, Category: Survey / Questionnaire; • flyerNew-converted.pdf, Category: Recruitment Materials; • GodspeedQuestionnaire.docx, Category: Survey / Questionnaire; • HRP-502 -Consent Document (Adult).pdf, Category: Consent Form; • HRP-503 -Protocol.docx, Category: IRB Protocol;

Page 1 of 2

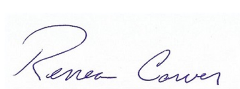
	• interaction related questionnaires.docx, Category: Survey / Questionnaire; • multi-dimensional emotoinal empathy scale.pdf, Category: Survey / Questionnaire; • NasaTLXShort.pdf, Category: Survey / Questionnaire; • PetAttitudeScale.pdf, Category: Survey / Questionnaire; • Social Presence Bailenson.docx, Category: Survey / Questionnaire; • state anxiety inventory.docx, Category: Survey / Questionnaire; • SupportFigureQuestionnaire.docx, Category: Survey / Questionnaire; • system usability scale.pdf, Category: Survey / Questionnaire; • task performance.docx, Category: Survey / Questionnaire; • the temple presence inventory.doc, Category: Survey / Questionnaire; • User experience questionnaire.pdf, Category: Survey / Questionnaire;

The IRB approved the protocol on 10/16/2019.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,



Renea Carver
Designated Reviewer

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A.7 Letter 7

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
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IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

October 23, 2019

Dear Nahal Norouzi:

On 10/23/2019, the IRB reviewed the following submission:

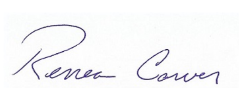
Type of Review:	Modification / Update
Title:	Perception of Virtual Animals in Augmented Reality as Social Support Figures
Investigator:	Nahal Norouzi
IRB ID:	MOD00000557
Funding:	Name: National Science Foundation (NSF), Grant Office ID: NSF award# 1800961; Name: Office of Naval Research, Grant Office ID: ONR award# N00014-17-1-2927
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	None

The IRB approved the protocol on 10/23/2019.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,



Renea Carver
Designated Reviewer

A.8 Letter 8

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

UNIVERSITY OF CENTRAL FLORIDA

APPROVAL

November 6, 2019

Dear Nahal Norouzi:

On 11/6/2019, the IRB reviewed the following submission:

Type of Review:	Modification / Update
Title:	Perception of Virtual Animals in Augmented Reality as Social Support Figures
Investigator:	Nahal Norouzi
IRB ID:	MOD00000586
Funding:	Name: National Science Foundation (NSF), Grant Office ID: NSF award# 1800961; Name: Office of Naval Research, Grant Office ID: ONR award# N00014-17-1-2927
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• HRP-502 -Consent Document (Adult).pdf, Category: Consent Form; • HRP-503 -Protocol.docx, Category: IRB Protocol;

The IRB approved the protocol from 11/6/2019.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Adrienne Showman
Designated Reviewer

Page 1 of 1

A.9 Letter 9

UCF

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

November 8, 2019

Dear Nahal Norouzi:

On 11/8/2019, the IRB reviewed the following submission:

Type of Review:	Modification / Update
Title:	Perception of Virtual Animals in Augmented Reality as Social Support Figures
Investigator:	Nahal Norouzi
IRB ID:	MOD00000600
Funding:	Name: Natl Science Fdn (NSF), Grant Office ID: NSF award# 1800961; Name: Ofc of Naval Research, Grant Office ID: ONR award# N00014-17-1-2927
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• HRP-503 -Protocol.docx, Category: IRB Protocol; • Panel Member Questionnaire.docx, Category: Survey / Questionnaire;

The IRB approved the protocol from 11/8/2019.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Adrienne Showman
Designated Reviewer

Page 1 of 1

A.10 Letter 10

UCF

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

Memorandum

To: Nahal Norouzi

From: UCF Institutional Review Board (IRB)

Date: October 8, 2021

Re: IRB Coverage

The IRB reviewed the information related to your dissertation.

Your project data is covered under the following protocol previously approved by the IRB. You are listed as a Sub-Investigator on the studies and your use of the data is consistent with the the protocol.

IRB study name	IRB Approval Number
The Effects of Realism Cues on Interactions with Human Surrogates	SBE-15-11405
Enhanced Perception and Cognition in Augmented Reality	SBE-17-13446

If you have any questions, please contact the UCF IRB irb@ucf.edu.

Sincerely,

Renea Carver

Renea Carver
IRB Manager

Page 1 of 1

A.11 Letter 11

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

August 11, 2021

Dear Gregory Welch:

On 8/11/2021, the IRB reviewed the following submission:

Type of Review:	Modification / Update: added six questionnaires; minor revisions to protocol, consent and flyer to reflect the new study timeline
Title:	The Effects of Realism Cues on Interactions with Human Surrogates
Investigator:	Gregory Welch
IRB ID:	MOD00002113
Funding:	Name: Ofc of Naval Research, Funding Source ID: ONR award# N00014-17-1- 2927; Name: Ofc of Naval Research, Funding Source ID: ONR award# N00014-21-1-2578; Name: Natl Science Fdn (NSF)
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• Copresence Basdogan.docx, Category: Survey / Questionnaire; • Flyer_HSI.pdf, Category: Recruitment Materials; • GodspeedQuestionnaire.docx, Category: Survey / Questionnaire; • HaloEffectEvaluation_Subjective.docx, Category: Survey / Questionnaire; • HRP-502 -Consent Document (Adult)-HSI.pdf, Category: Consent Form; • HRP-503 -Protocol-HSI.docx, Category: IRB Protocol; • PetAttitudeScale.pdf, Category: Survey / Questionnaire; • Social Presence Bailenson.docx, Category: Survey / Questionnaire; • the temple presence inventory.doc, Category: Survey / Questionnaire;

The IRB approved the protocol from 8/11/2021 to 6/27/2022.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. Guidance on submitting Modifications and a Continuing Review or Administrative Check-in are detailed in the manual. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Renea Carver

Renea Carver
Designated Reviewer

A.12 Letter 12

UCF

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

February 23, 2021

Dear Gregory Welch:

On 2/23/2021, the IRB reviewed the following submission:

Type of Review:	Modification / Update to study instruments
Title:	Enhanced Perception and Cognition in Augmented Reality
Investigator:	Gregory Welch
IRB ID:	MOD00001660
Funding:	Name: Ofc of Naval Research, Funding Source ID: ONR award# N00014-17-1-2927
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• 360 VR Experience Questionnaire • Protocol

The IRB approved the protocol from 2/23/2021 to 3/25/2021.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. Guidance on submitting Modifications and a Continuing Review or Administrative Check-in are detailed in the manual. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Renea Carver
Designated Reviewer

A.13 Letter 13

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

March 24, 2021

Dear Gregory Welch:

On 3/24/2021, the IRB reviewed the following submission:

Type of Review:	Continuing Review, SBE-17-13446: Expedited Review Categories 6 & 7, Waiver of Documentation of Consent
Title:	Enhanced Perception and Cognition in Augmented Reality
Investigator:	Gregory Welch
IRB ID:	CR00000992
Funding:	Name: Ofc of Naval Research, Funding Source ID: ONR award# N00014-17-1-2927
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	None

The IRB approved the protocol from 3/24/2021 to 3/23/2022.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. Guidance on submitting Modifications and a Continuing Review or Administrative Check-in are detailed in the manual. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Renea Carver

Renea Carver
Designated Reviewer

Page 1 of 1

LIST OF REFERENCES

[1] 5 lessons learned while making lost — oculus. https://www.oculus.com/story-studio/blog/5-lessons-learned-while-making-lost/. [Accessed 2021-21-11].

[2] The Cornell Lab of Ornithology. All About Birds. https://www.allaboutbirds.org/guide/Blue_Jay/id. [Accessed 2021-04-01].

[3] 4EXPERIENCE. HoloLens 2 vs HoloLens 1: what's new? https://4experience.co/hololens-2-vs-hololens-1-whats-new/. [Accessed 2021-21-11].

[4] ABEELE, M. M. V., ANTHEUNIS, M. L., AND SCHOUTEN, A. P. The effect of mobile messaging during a conversation on impression formation and interaction quality. *Computers in Human Behavior 62* (2016), 562–569.

[5] ADOBE MIXAMO. Animate 3D characters for games, film, and more. https://www.mixamo.com/. [Accessed 2021-21-11].

[6] AHN, S. J., JOHNSEN, K., MOORE, J., BROWN, S., BIERSMITH, M., AND BALL, C. Using virtual pets to increase fruit and vegetable consumption in children: A technology-assisted social cognitive theory approach. *Cyberpsychology, Behavior, and Social Networking 19*, 2 (2016), 86–92.

[7] AHN, S. J., JOHNSEN, K., ROBERTSON, T., MOORE, J., BROWN, S., MARABLE, A., AND BASU, A. Using virtual pets to promote physical activity in children: An application of the youth physical activity promotion model. *Journal of health communication 20*, 7 (2015), 807–815.

[8] ALLEN, C., PRAGANTHA, J., AND HARIS, D. A. 3d virtual pet game" moar" with augmented reality to simulate pet raising scenario on mobile device. In *2014 International Conference on Advanced Computer Science and Information System* (2014), IEEE, pp. 414–419.

[9] ALLEN, K., BLASCOVICH, J., AND MENDES, W. B. Cardiovascular reactivity and the presence of pets, friends, and spouses: The truth about cats and dogs. *Psychosomatic medicine 64*, 5 (2002), 727–739.

[10] AMRY, M., WHITE, C., MCCLELLAN, D., AND VARAKIN, D. A. With this tilt, i dub you cute: Head tilt increases cuteness in puppies and adult dogs. *Journal of Vision 18*, 10 (2018), 1275–1275.

[11] ANABUKI, M., KAKUTA, H., YAMAMOTO, H., AND TAMURA, H. Welbo: An embodied conversational agent living in mixed reality space. In *CHI'00 Extended Abstracts on Human Factors in Computing Systems* (2000), pp. 10–11.

[12] APPA. Pet industry market size, trends & ownership statistics. `https://www.americanpetproducts.org/press_industrytrends.asp`, March 2021. [Accessed 2021-21-11].

[13] ARAMAKI, R., AND MURAKAMI, M. Investigating appropriate spatial relationship between user and ar character agent for communication using ar woz system. In *Proceedings of the 15th ACM on International Conference on Multimodal Interaction* (2013), pp. 397–404.

[14] ARGELAGUET SANZ, F., OLIVIER, A.-H., BRUDER, G., PETTRE, J., AND LECUYER, A. Virtual Proxemics: Locomotion in the Presence of Obstacles in Large Immersive Projection Environments. In *IEEE Virtual Reality* (2015), pp. 75–80.

[15] ARON, A., ARON, E. N., AND SMOLLAN, D. Inclusion of other in the self scale and the structure of interpersonal closeness. *Journal of personality and social psychology 63*, 4 (1992), 596.

[16] ARUANNO, B., GARZOTTO, F., TORELLI, E., AND VONA, F. Hololearn: Wearable mixed reality for people with neurodevelopmental disorders (ndd). In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility* (2018), pp. 40–51.

[17] ASHLEY, J. Magic leap one vs hololens v1 comparison. `https://www.imaginativeuniversal.com/blog/2018/10/08/magic-leap-one-vs-hololens-v1-comparison/`, October 2018. [Accessed 2021-21-11].

[18] ASPCA. 7 Tips on Canine Body Language. `https://www.aspcapro.org/resource/7-tips-canine-body-language`. [Accessed 2021-21-11].

[19] AUDACITY. Free, open source, cross-platform audio software. `https://www.audacityteam.org/`. [Accessed 2021-21-11].

[20] AUTODESK. 3D computer animation, modeling, simulation, and rendering software. `https://www.autodesk.com/products/maya/`. [Accessed 2021-21-11].

[21] BAILENSON, J. N., BEALL, A. C., AND BLASCOVICH, J. Gaze and task performance in shared virtual environments. *The journal of visualization and computer animation 13*, 5 (2002), 313–320.

[22] BAILENSON, J. N., BLASCOVICH, J., BEALL, A. C., AND LOOMIS, J. M. Interpersonal distance in immersive virtual environments. *Personality and Social Psychology Bulletin 29*, 7 (2003), 819–833.

[23] BARBER, O., AND PROOPS, L. Low-ability secondary school students show emotional, motivational, and performance benefits when reading to a dog versus a teacher. *Anthrozoös 32*, 4 (2019), 503–518.

[24] BARKER, R. T., KNISELY, J. S., BARKER, S. B., COBB, R. K., AND SCHUBERT, C. M. Preliminary investigation of employee's dog presence on stress and organizational perceptions. *International Journal of Workplace Health Management 5*, 1 (2012), 15–30.

[25] BARKER, S. B., BARKER, R. T., MCCAIN, N. L., AND SCHUBERT, C. M. A randomized cross-over exploratory study of the effect of visiting therapy dogs on college student stress before final exams. *Anthrozoös 29*, 1 (2016), 35–46.

[26] BARKER, S. B., KNISELY, J. S., MCCAIN, N. L., SCHUBERT, C. M., AND PANDURANGI, A. K. Exploratory study of stress-buffering response patterns from interaction with a therapy dog. *Anthrozoös 23*, 1 (2010), 79–91.

[27] BARTNECK, C., CROFT, E., AND KULIC, D. Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *International Journal of Social Robotics 1*, 1 (2009), 71–81.

[28] BASDOGAN, C., HO, C.-H., SRINIVASAN, M. A., AND SLATER, M. An experimental study on the role of touch in shared virtual environments. *ACM Transactions on Computer-Human Interaction 7*, 4 (2000), 443–460.

[29] BECK, A. M., AND KATCHER, A. H. Future directions in human-animal bond research. *American Behavioral Scientist 47*, 1 (2003), 79–93.

[30] BEETZ, A., UVNÄS-MOBERG, K., JULIUS, H., AND KOTRSCHAL, K. Psychosocial and psychophysiological effects of human-animal interactions: the possible role of oxytocin. *Frontiers in psychology 3* (2012), 234.

[31] BENSKY, M. K., GOSLING, S. D., AND SINN, D. L. The world from a dog's point of view: a review and synthesis of dog cognition research. In *Advances in the Study of Behavior*, vol. 45. Elsevier, 2013, pp. 209–406.

[32] BETHEL, C. L., HENKEL, Z., DARROW, S., AND BAUGUS, K. Therabot-an adaptive therapeutic support robot. In *IEEE World Symposium on Digital Intelligence for Systems and Machines* (2018), pp. 23–30.

[33] BICKMORE, T., SCHULMAN, D., AND YIN, L. Engagement vs. deceit: Virtual humans with human autobiographies. In *International workshop on intelligent virtual agents* (2009), Springer, pp. 6–19.

[34] BIOCCA, F., HARMS, C., AND GREGG, J. The networked minds measure of social presence: Pilot test of the factor structure and concurrent validity. In *4th annual international workshop on presence, Philadelphia, PA* (2001), pp. 1–9.

[35] BIOCCA, F., AND NOWAK, K. Plugging your body into the telecommunication system: Mediated embodiment, media interfaces, and social virtual environments. *Communication technology and society* (2001), 407–447.

[36] BIOCCA, F., OWEN, C., TANG, A., AND BOHIL, C. Attention issues in spatial information systems: Directing mobile users' visual attention using augmented reality. *Journal of Management Information Systems 23*, 4 (2007), 163–184.

[37] BLACKHART, G. C., NELSON, B. C., KNOWLES, M. L., AND BAUMEISTER, R. F. Rejection elicits emotional reactions but neither causes immediate distress nor lowers self-esteem: A meta-analytic review of 192 studies on social exclusion. *Personality and Social Psychology Review 13*, 4 (2009), 269–309.

[38] BLASCOVICH, J. Social influence within immersive virtual environments. In *The Social Life of Avatars*, R. Schroeder, Ed., Computer Supported Cooperative Work. Springer London, 2002, pp. 127–145.

[39] BLASCOVICH, J., LOOMIS, J., BEALL, A. C., SWINTH, K. R., HOYT, C. L., AND BAILENSON, J. N. Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry 13*, 2 (2002), 103 – 124.

[40] BLOOM, T., AND FRIEDMAN, H. Classifying dogs'(canis familiaris) facial expressions from photographs. *Behavioural Processes 96* (2013), 1–10.

[41] BORGI, M., AND CIRULLI, F. Pet face: Mechanisms underlying human-animal relationships. *Frontiers in psychology 7* (2016), 298.

[42] BORK, F., SCHNELZER, C., ECK, U., AND NAVAB, N. Towards efficient visual guidance in limited field-of-view head-mounted displays. *IEEE transactions on visualization and computer graphics 24*, 11 (2018), 2983–2992.

[43] BRADSHAW, J., AND ROONEY, N. Dog social behaviour and communication. *The Domestic Dog: Its Evolution, Behavior and Interactions with People. Cambridge University Press Cambridge (UK)* (2017), 133–159.

[44] BRAUN, V., AND CLARKE, V. Using thematic analysis in psychology. *Qualitative research in psychology 3*, 2 (2006), 77–101.

[45] BROOKS, H. L., RUSHTON, K., LOVELL, K., BEE, P., WALKER, L., GRANT, L., AND ROGERS, A. The power of support from companion animals for people living with mental health problems: a systematic review and narrative synthesis of the evidence. *BMC psychiatry 18*, 1 (2018), 1–12.

[46] BROOKS, H. L., RUSHTON, K., LOVELL, K., BEE, P., WALKER, L., GRANT, L., AND ROGERS, A. The power of support from companion animals for people living with mental health problems: a systematic review and narrative synthesis of the evidence. *BMC Psychiatry 18*, 1 (2018).

[47] BROOM, D. M. The evolution of morality. *Applied Animal Behaviour Science 100*, 1-2 (2006), 20–28.

[48] BROOM, D. M. Cognitive ability and awareness in domestic animals and decisions about obligations to animals. *Applied Animal Behaviour Science 126*, 1-2 (2010), 1–11.

[49] BURDETTE, M. The Swayze Effect. `https://www.oculus.com/story-studio/blog/the-swayze-effect/?locale=en_US`. [Accessed 2021-21-11].

[50] BYD. BYD Qin plug-in hybrid car has an in-dash robot to keep you company. `https://www.theverge.com/2012/4/23/2968502/byd-qin-robot-beijing-auto-show-aida-robotic-assistant`. [Accessed 2021-21-11].

[51] BYRNE, S., GAY, G., POLLACK, J., GONZALES, A., RETELNY, D., LEE, T., AND WANSINK, B. Caring for mobile phone-based virtual pets can influence youth eating behaviors. *Journal of Children and Media 6*, 1 (2012), 83–99.

[52] BÖNSCH, A., KIES, A., JÖRLING, M., PALUCH, S., AND KUHLEN, T. W. An empirical lab study investigating if higher levels of immersion increase the willingness to donate. In *2019 IEEE Virtual Humans and Crowds for Immersive Environments (VHCIE)* (2019), pp. 1–4.

[53] Cao, C., Shi, Z., and Yu, M. Automatic generation of diegetic guidance in cinematic virtual reality. In *2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (2020), IEEE, pp. 600–607.

[54] Carrozzino, M. A., Galdieri, R., Machidon, O. M., and Bergamasco, M. Do virtual humans dream of digital sheep? *IEEE Computer Graphics and Applications 40*, 4 (2020), 71–83.

[55] Chao, T.-Y., and Lin, S.-F. A mixed reality system to improve walking experience. In *Proceedings of the IEEE International Conference on System Science and Engineering (ICSSE)* (2018), pp. 1–4.

[56] Chen, Z.-H., Chou, C.-Y., Deng, Y.-C., and Chan, T.-W. Active open learner models as animal companions: Motivating children to learn through interacting with my-pet and our-pet. *International Journal of Artificial Intelligence in Education 17*, 2 (2007), 145–167.

[57] Chen, Z.-H., Deng, Y.-C., Chou, C.-Y., and Chan, T.-W. Motivating learners by nurturing animal companions: My-pet and our-pet. In *AIED* (2005), pp. 136–143.

[58] Chesney, T., and Lawson, S. The illusion of love: Does a virtual pet provide the same companionship as a real one? *Interaction Studies 8*, 2 (2007), 337–342.

[59] Chotpitayasunondh, V., and Douglas, K. M. The effects of "phubbing" on social interaction. *Journal of Applied Social Psychology 48*, 6 (2018), 304–316.

[60] Christenfeld, N., Gerin, W., Linden, W., Sanders, M., Mathur, J., Deich, J. D., and Pickering, T. G. Social support effects on cardiovascular reactivity: is a stranger as effective as a friend? *Psychosomatic medicine 59*, 4 (1997), 388–398.

[61] Cohen, J. *Statistical power analysis for the behavioral sciences*. Routledge, 2013.

[62] COLARELLI, S. M., MCDONALD, A. M., CHRISTENSEN, M. S., AND HONTS, C. A companion dog increases prosocial behavior in work groups. *Anthrozoös 30*, 1 (2017), 77–89.

[63] COLLINS, S. *Tail Talk: Understanding the Secret Language of Dogs*. Chronicle Books, 2007.

[64] COPPINGER, R., AND COPPINGER, L. *Dogs: A Startling New Understanding of Canine Origin, Behavior & Evolution*, 1st ed. Scribner, 2001.

[65] CORDAR, A., WENDLING, A., WHITE, C., LAMPOTANG, S., AND LOK, B. Repeat after me: Using mixed reality humans to influence best communication practices. In *Proceedings of the IEEE Virtual Reality* (2017), pp. 148–156.

[66] DAHER, S., HOCHREITER, J., NOROUZI, N., GONZALEZ, L., BRUDER, G., AND WELCH, G. Physical-virtual agents for healthcare simulation. In *Proceedings of the ACM International Conference on Intelligent Virtual Agents* (2018), pp. 99–106.

[67] DAHER, S., HOCHREITER, J., NOROUZI, N., SCHUBERT, R., BRUDER, G., GONZALEZ, L., ANDERSON, M., DIAZ, D., CENDAN, J., AND WELCH, G. [POSTER] Matching vs. Non-Matching Visuals and Shape for Embodied Virtual Healthcare Agents. In *IEEE Virtual Reality* (2019).

[68] DAHER, S., KIM, K., LEE, M., BRUDER, G., SCHUBERT, R., BAILENSON, J., AND WELCH, G. [poster] can social presence be contagious? effects of social presence priming on interaction with virtual humans. In *3D User Interfaces (3DUI), 2017 IEEE Symposium on* (2017).

[69] DAHER, S., KIM, K., LEE, M., RAIJ, A., SCHUBERT, R., BAILENSON, J., AND WELCH, G. [poster] exploring social presence transfer in real-virtual human interaction. In *Proceedings of IEEE Virtual Reality 2016* (Greenville, SC, USA, 2016).

[70] DAHER, S., KIM, K., LEE, M., SCHUBERT, R., BRUDER, G., BAILENSON, J., AND WELCH, G. *Effects of Social Priming on Social Presence with Intelligent Virtual Agents*, vol. 10498. Springer International Publishing, 2017, pp. 87–100.

[71] DAHLBÄCK, N., JÖNSSON, A., AND AHRENBERG, L. Wizard of oz studies — why and how. *Knowledge-Based Systems 6*, 4 (1993), 258–266. Special Issue: Intelligent User Interfaces.

[72] DAMIAN, I., KISTLER, F., OBAID, M., BUHLING, R., BILLINGHURST, M., AND ANDRE, E. Motion capturing empowered interaction with a virtual agent in an Augmented Reality environment. In *Extended Abstracts of the IEEE International Symposium on Mixed and Augmented Reality* (2013), pp. 1–6.

[73] DEMIRIS, G., THOMPSON, H. J., LAZAR, A., AND LIN, S.-Y. Evaluation of a digital companion for older adults with mild cognitive impairment. In *AMIA Annual Symposium Proceedings* (2016), vol. 2016, American Medical Informatics Association, p. 496.

[74] DEY, A., BILLINGHURST, M., LINDEMAN, R. W., AND SWAN, J. A systematic review of 10 years of augmented reality usability studies: 2005 to 2014. *Frontiers in Robotics and AI 5* (2018), 37.

[75] DIGITAL DREAM LABS. Cozmo. `https://www.digitaldreamlabs.com/`. [Accessed 2021-21-11].

[76] DILLAHUNT, T., BECKER, G., MANKOFF, J., AND KRAUT, R. Motivating environmentally sustainable behavior changes with a virtual polar bear. In *Pervasive 2008 Workshop Proceedings* (2008), vol. 8, pp. 58–62.

[77] DIMENSIONS. Beagle Dog Dimensions. `https://www.dimensions.com/element/dogs-beagle`. [Accessed 2021-21-11].

[78] DOW, S., MEHTA, M., HARMON, E., MACINTYRE, B., AND MATEAS, M. Presence and engagement in an interactive drama. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2007), p. 1475–1484.

[79] DOW, S., MEHTA, M., LAUSIER, A., MACINTYRE, B., AND MATEAS, M. Initial lessons from ar façade, an interactive augmented reality drama. In *Proceedings of the ACM SIGCHI International Conference on Advances in Computer Entertainment Technology* (2006).

[80] DRAGONE, M., HOLZ, T., AND O'HARE, G. M. Using mixed reality agents as social interfaces for robots. In *Proceedings of the 16th IEEE International Symposium on Robot and Human Interactive Communication* (2007), pp. 1161–1166.

[81] DUCKWORTH, D., HENKEL, Z., WUISAN, S., COGLEY, B., COLLINS, C., AND BETHEL, C. L. Therabot: The initial design of a robotic therapy support system. In *HRI (Extended Abstracts)* (2015), pp. 13–14.

[82] ELGIER, A. M., JAKOVCEVIC, A., BARRERA, G., MUSTACA, A. E., AND BENTOSELA, M. Communication between domestic dogs (canis familiaris) and humans: dogs are good learners. *Behavioural processes 81*, 3 (2009), 402–408.

[83] ERICKSON, A., KIM, K., BRUDER, G., AND WELCH, G. Exploring the Limitations of Environment Lighting on Optical See-Through Head-Mounted Displays. In *Proceedings of the ACM Symposium on Spatial User Interaction* (2020).

[84] Faul, F., Erdfelder, E., Lang, A.-G., and Buchner, A. G* power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior research methods 39*, 2 (2007), 175–191.

[85] Fearghail, C. O., Ozcinar, C., Knorr, S., and Smolic, A. Director's cut-analysis of aspects of interactive storytelling for vr films. In *International Conference on Interactive Digital Storytelling* (2018), Springer, pp. 308–322.

[86] Felnhofer, A., Kaufmann, M., Atteneder, K., Kafka, J. X., Hlavacs, H., Beutl, L., Hennig-Fast, K., and Kothgassner, O. D. The mere presence of an attentive and emotionally responsive virtual character influences focus of attention and perceived stress. *International Journal of Human-Computer Studies 132* (2019), 45–51.

[87] Fong, T., Nourbakhsh, I., and Dautenhahn, K. A Survey of Socially Interactive Robots. *Robotics and Autonomous Systems 42*, 3-4 (2003), 143–166.

[88] Fontana, A. M., Diegnan, T., Villeneuve, A., and Lepore, S. J. Nonevaluative social support reduces cardiovascular reactivity in young women during acutely stressful performance situations. *Journal of Behavioral Medicine 22*, 1 (1999), 75–91.

[89] Friedmann, E., Katcher, A. H., Thomas, S. A., Lynch, J. J., and Messent, P. R. Social interaction and blood pressure: influence of animal companions. *Journal of Nervous and Mental Disease* (1983).

[90] Gee, N. R., Friedmann, E., Coglitore, V., Fisk, A., and Stendahl, M. Does physical contact with a dog or person affect performance of a working memory task? *Anthrozoös 28*, 3 (2015), 483–500.

[91] Gee, N. R., Mueller, M. K., and Curl, A. L. Human–animal interaction and older adults: An overview. *Frontiers in psychology 8* (2017), 1416.

[92] GIBEAULT, S. Why do dogs tilt their heads? https://www.akc.org/expert-advice/lifestyle/why-do-dogs-tilt-their-heads/, June 2019. [Accessed 2021-21-11].

[93] GIL, K., RHIM, J., HA, T., DOH, Y. Y., AND WOO, W. AR Petite Theater: Augmented Reality Storybook for Supporting Children's Empathy Behavior. In *Proceedings of the IEEE International Symposium on Mixed and Augmented Reality - Media, Art, Social Science, Humanities and Design (ISMAR-MASH'D)* (2014), pp. 13–20.

[94] GONZALES, A. L., AND WU, Y. Public cellphone use does not activate negative responses in others… unless they hate cellphones. *Journal of Computer-Mediated Communication 21*, 5 (2016), 384–398.

[95] GOSLOW, G., SEEHERMAN, H., TAYLOR, C., MCCUTCHIN, M., AND HEGLUND, N. Electrical activity and relative length changes of dog limb muscles as a function of speed and gait. *Journal of Experimental Biology 94*, 1 (1981), 15–42.

[96] GRAVROK, J., HOWELL, T., BENDRUPS, D., AND BENNETT, P. Thriving through relationships: Assistance dogs' and companion dogs' perceived ability to contribute to thriving in individuals with and without a disability. *Disability and Rehabilitation: Assistive Technology* (2019).

[97] GROSSBERG, J. M., AND ALF, E. F. Interaction with pet dogs: Effects on human cardiovascular response. *Journal of the Delta Society* (1985).

[98] GUÉGUEN, N., AND CICCOTTI, S. Domestic dogs as facilitators in social interaction: An evaluation of helping and courtship behaviors. *Anthrozoös 21*, 4 (2008), 339–349.

[99] Gushima, K., Akasaki, H., and Nakajima, T. Ambient bot: delivering daily casual information through eye contact with an intimate virtual creature. In *Proceedings of the 21st International Academic Mindtrek Conference* (2017), pp. 231–234.

[100] Gussgard, A. M., Weese, J. S., Hensten, A., and Jokstad, A. Dog-assisted therapy in the dental clinic: Part a—hazards and assessment of potential risks to the health and safety of humans. *Clinical and Experimental Dental Research 5*, 6 (2019), 692–700.

[101] Haesler, S., Kim, K., Bruder, G., and Welch, G. Seeing is believing: Improving the perceived trust in visually embodied alexa in augmented reality. In *Proceedings of the IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)* (2018), pp. 204–205.

[102] Hall, E. T. A system for the notation of proxemic behavior 1. *American anthropologist 65*, 5 (1963), 1003–1026.

[103] Hall, E. T. *The Hidden Dimension*. Anchor Books, 1990.

[104] Hart, L. A., Hart, B. L., and Bergin, B. L. Socializing effects of service dogs for people with disabilities. *Anthrozoös 1*, 1 (1987), 41–44.

[105] Herbst, K. C., Gaertner, L., and Insko, C. A. My head says yes but my heart says no: Cognitive and affective attraction as a function of similarity to the ideal self. *Journal of personality and social psychology 84*, 6 (2003), 1206.

[106] Immersiv.io. Hands-on Microsoft's HoloLens 2: Review by Immersiv.io' team. `https://www.immersiv.io/blog/hands-on-hololens-2-review/`. [Accessed 2021-21-11].

[107] Isenstein, S. *Man's Best Friend is a Therapist's Best Friend: How the Presence of a Dog Influences Therapists and Others' Perceptions of Them*. PhD thesis, 2018.

[108] JOHNSEN, K., AHN, S. J., MOORE, J., BROWN, S., ROBERTSON, T. P., MARABLE, A., AND BASU, A. Mixed reality virtual pets to reduce childhood obesity. *IEEE transactions on visualization and computer graphics 20*, 4 (2014), 523–530.

[109] JONES, K. E., DASHFIELD, K., DOWNEND, A. B., AND OTTO, C. M. Search-and-rescue dogs: an overview for veterinarians. *Journal of the American Veterinary Medical Association 225*, 6 (2004), 854–860.

[110] JUDD, C. M., WESTFALL, J., AND KENNY, D. A. Treating stimuli as a random factor in social psychology: A new and comprehensive solution to a pervasive but largely ignored problem. *Journal of personality and social psychology 103*, 1 (2012), 54.

[111] KAMINSKI, J., AND MARSHALL-PESCINI, S. *The social dog: behavior and cognition*. Elsevier, 2014.

[112] KANE, H. S., MCCALL, C., COLLINS, N. L., AND BLASCOVICH, J. Mere presence is not enough: Responsive support in a virtual world. *Journal of experimental social psychology 48*, 1 (2012), 37–44.

[113] KANG, J., AND WEI, L. " give me the support i want!" the effect of matching an embodied conversational agent's social support to users' social support needs in fostering positive user-agent interaction. In *Proceedings of the 6th International Conference on Human-Agent Interaction* (2018), pp. 106–113.

[114] KANG, S.-H., AND GRATCH, J. Virtual humans elicit socially anxious interactants' verbal self-disclosure. *Computer Animation and Virtual Worlds 21*, 3-4 (2010), 473–482.

[115] KELLERT, S. R., AND WILSON, E. O. *The biophilia hypothesis*. Island Press, 1995.

[116] KENNEDY, R. S., LANE, N. E., BERBAUM, K. S., AND LILIENTHAL, M. G. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology 3*, 3 (1993), 203–220.

[117] KEREPESI, A., KUBINYI, E., JONSSON, G., MAGNUSSON, M., AND MIKLOSI, A. Behavioural comparison of human–animal (dog) and human–robot (aibo) interactions. *Behavioural processes 73*, 1 (2006), 92–99.

[118] KERN, F., WINTER, C., GALL, D., KÄTHNER, I., PAULI, P., AND LATOSCHIK, M. E. Immersive virtual reality and gamification within procedurally generated environments to increase motivation during gait rehabilitation. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (2019), IEEE, pp. 500–509.

[119] KERTES, D. A., LIU, J., HALL, N. J., HADAD, N. A., WYNNE, C. D., AND BHATT, S. S. Effect of pet dogs on children's perceived stress and cortisol stress response. *Social Development 26*, 2 (2017), 382–401.

[120] KIM, H. S., SHERMAN, D. K., AND TAYLOR, S. E. Culture and social support. *American psychologist 63*, 6 (2008), 518.

[121] KIM, K. Improving Social Presence with a Virtual Human via Multimodal Physical–Virtual Interactivity in AR. In *Extended Abstracts of the ACM CHI Conference on Human Factors in Computing Systems (Student Research Competition)* (2018), pp. SRC09:1–6.

[122] KIM, K., BILLINGHURST, M., BRUDER, G., DUH, H. B.-L., AND WELCH, G. F. Revisiting Trends in Augmented Reality Research: A Review of the 2nd Decade of ISMAR (2008–2017). *IEEE Transactions on Visualization and Computer Graphics 24*, 11 (2018), 2947–2962.

[123] KIM, K., BOELLING, L., HAESLER, S., BAILENSON, J. N., BRUDER, G., AND WELCH, G. F. Does a Digital Assistant Need a Body? The Influence of Visual Embodiment and Social Behavior on the Perception of Intelligent Virtual Agents in AR. In *Proceedings of the IEEE International Symposium on Mixed and Augmented Reality* (2018), pp. 105–114.

[124] KIM, K., BRUDER, G., AND WELCH, G. Exploring the effects of observed physicality conflicts on real-virtual human interaction in augmented reality. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology* (2017), ACM, p. 31.

[125] KIM, K., BRUDER, G., AND WELCH, G. Exploring the Effects of Observed Physicality Conflicts on Real–Virtual Human Interaction in Augmented Reality. In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology* (2017), pp. 31:1–7.

[126] KIM, K., BRUDER, G., AND WELCH, G. F. Blowing in the wind: Increasing copresence with a virtual human via airflow influence in augmented reality. In *International Conference on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments* (2018), pp. 183–190.

[127] KIM, K., BRUDER, G., AND WELCH, G. F. Blowing in the wind: Increasing copresence with a virtual human via airflow influence in augmented reality. In *Proceedings of ICAT-EGVE* (2018), pp. 183–190.

[128] KIM, K., DE MELO, C. M., NOROUZI, N., BRUDER, G., AND WELCH, G. F. Reducing Task Load with an Embodied Intelligent Virtual Assistant for Improved Performance in Collaborative Decision Making. In *Proceedings of the IEEE Conference on Virtual Reality and 3D User Interfaces* (2020), pp. 529–538.

[129] KIM, K., MALONEY, D., BRUDER, G., BAILENSON, J. N., AND WELCH, G. F. The effects of virtual human's spatial and behavioral coherence with physical objects on social presence in AR, 2017.

[130] Kim, K., Maloney, D., Bruder, G., Bailenson, J. N., and Welch, G. F. The effects of virtual human's spatial and behavioral coherence with physical objects on social presence in AR. *Computer Animation and Virtual Worlds 28*, 3-4 (2017), e1771.

[131] Kim, K., Norouzi, N., Losekamp, T., Bruder, G., Anderson, M., and Welch, G. Effects of patient care assistant embodiment and computer mediation on user experience. In *Proceedings of the IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)* (2019), IEEE, pp. 17–24.

[132] Kim, K., Schubert, R., Hochreiter, J., Bruder, G., and Welch, G. Blowing in the wind: Increasing social presence with a virtual human via environmental airflow interaction in mixed reality. *Computers & Graphics 83* (Oct 2019), 23–32.

[133] Kirschbaum, C., Pirke, K.-M., and Hellhammer, D. H. The 'trier social stress test'–a tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology 28*, 1-2 (1993), 76–81.

[134] Knapp, T. R. Treating ordinal scales as interval scales: an attempt to resolve the controversy. *Nursing Research 39*, 2 (1990), 121–123.

[135] Kothgassner, O. D., Goreis, A., Kafka, J. X., Kaufmann, M., Atteneder, K., Beutl, L., Hennig-Fast, K., Hlavacs, H., and Felnhofer, A. Virtual social support buffers stress response: An experimental comparison of real-life and virtual support prior to a social stressor. *Journal of behavior therapy and experimental psychiatry 63* (2019), 57–65.

[136] Kramer, S. C., Friedmann, E., and Bernstein, P. L. Comparison of the effect of human interaction, animal-assisted therapy, and aibo-assisted therapy on long-term care residents with dementia. *Anthrozoös 22*, 1 (2009), 43–57.

[137] KUJALA, M. V., SOMPPI, S., JOKELA, M., VAINIO, O., AND PARKKONEN, L. Human empathy, personality and experience affect the emotion ratings of dog and human facial expressions. *PloS one 12*, 1 (2017), e0170730.

[138] KUZON JR, W. M., URBANCHEK, M. G., AND MCCABE, S. The seven deadly sins of statistical analysis. *Annals of Plastic Surgery 37*, 3 (1996), 265–272.

[139] LAKATOS, G., AND MIKLÓSI, Á. How can the ethological study of dog-human companionship inform social robotics? In *Crossing Boundaries*. Brill, 2012, pp. 187–208.

[140] LAMBERT, A., NOROUZI, N., BRUDER, G., AND WELCH, G. A systematic review of ten years of research on human interaction with social robots. *International Journal of Human–Computer Interaction 36*, 19 (2020), 1804–1817.

[141] LANG, Y., LIANG, W., AND YU, L.-F. Virtual Agent Positioning Driven by Scene Semantics in Mixed Reality. In *Proceedings of the IEEE Conference on Virtual Reality and 3D User Interfaces* (2019), pp. 767–775.

[142] LANGE, D., STRATMANN, T. C., GRUENEFELD, U., AND BOLL, S. Hivefive: Immersion preserving attention guidance in virtual reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (2020), pp. 1–13.

[143] LEE, M., BRUDER, G., HÖLLERER, T., AND WELCH, G. Effects of unaugmented periphery and vibrotactile feedback on proxemics with virtual humans in ar. *IEEE transactions on visualization and computer graphics 24*, 4 (2018), 1525–1534.

[144] LEE, M., BRUDER, G., HÖLLERER, T., AND WELCH, G. Effects of Unaugmented Periphery and Vibrotactile Feedback on Proxemics with Virtual Humans in AR. *IEEE Transactions on Visualization and Computer Graphics 24*, 4 (2018), 1525–1534.

[145] LEE, M., KIM, K., DAHER, S., RAIJ, A., SCHUBERT, R., BAILENSON, J., AND WELCH, G. The Wobbly Table: Increased Social Presence via Subtle Incidental Movement of a Real-Virtual Table. In *Proceedings of the IEEE Virtual Reality* (2016), pp. 11–17.

[146] LEE, M., NOROUZI, N., BRUDER, G., WISNIEWSKI, P., AND WELCH, G. Mixed reality tabletop gameplay: Social interaction with a virtual human capable of physical influence. *IEEE Transactions on Visualization and Computer Graphics (TVCG)* (2019).

[147] LEE, M., NOROUZI, N., BRUDER, G., WISNIEWSKI, P. J., AND WELCH, G. F. The physical-virtual table: Exploring the effects of a virtual human's physical influence on social interaction. In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology* (2018), pp. 25:1–11.

[148] LEE, M., NOROUZI, N., BRUDER, G., WISNIEWSKI, P. J., AND WELCH, G. F. The Physical-Virtual Table: Exploring the Effects of a Virtual Human's Physical Influence on Social Interaction. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology* (2018), pp. 1–11.

[149] LEE, M., NOROUZI, N., BRUDER, G., WISNIEWSKI, P. J., AND WELCH, G. F. Mixed Reality Tabletop Gameplay: Social Interaction with a Virtual Human Capable of Physical Influence. *IEEE Transactions on Visualization and Computer Graphics 24*, 8 (2019), 1–12.

[150] LI, B. J., BAILENSON, J. N., PINES, A., GREENLEAF, W. J., AND WILLIAMS, L. M. A public database of immersive VR videos with corresponding ratings of arousal, valence, and correlations between head movements and self report measures. *Frontiers in Psychology 8* (2017).

[151] LI, C., ANDROULAKAKI, T., GAO, A. Y., YANG, F., SAIKIA, H., PETERS, C., AND SKANTZE, G. Effects of posture and embodiment on social distance in human-agent in-

teraction in mixed reality. In *Proceedings of the 18th ACM International Conference on Intelligent Virtual Agents* (2018), pp. 191–196.

[152] LIBERATI, A., ALTMAN, D. G., TETZLAFF, J., MULROW, C., GØTZSCHE, P. C., IOANNIDIS, J. P., CLARKE, M., DEVEREAUX, P. J., KLEIJNEN, J., AND MOHER, D. The prisma statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Annals of Internal Medicine 151*, 4 (2009), W–65.

[153] LIN, C., FAAS, T., AND BRADY, E. Exploring affection-oriented virtual pet game design strategies in vr attachment, motivations and expectations of users of pet games. In *2017 Seventh International Conference on Affective Computing and Intelligent Interaction (ACII)* (2017), IEEE, pp. 362–369.

[154] LIN, J. J., MAMYKINA, L., LINDTNER, S., DELAJOUX, G., AND STRUB, H. B. Fish'n'steps: Encouraging physical activity with an interactive computer game. In *International conference on ubiquitous computing* (2006), Springer, pp. 261–278.

[155] LIVOREIL, B., GLANVILLE, J., HADDAWAY, N. R., BAYLISS, H., BETHEL, A., DE LACHAPELLE, F. F., ROBALINO, S., SAVILAAKSO, S., ZHOU, W., PETROKOFSKY, G., ET AL. Systematic searching for environmental evidence using multiple tools and sources. *Environmental Evidence 6*, 1 (2017), 1–14.

[156] LLERA, R., AND BUZHARDT, L. Why dogs tilt their heads. `https://vcahospitals.com/know-your-pet/why-dogs-tilt-their-heads`, May 2021. [Accessed 2021-21-11].

[157] LOPATOVSKA, I., RINK, K., KNIGHT, I., RAINES, K., COSENZA, K., WILLIAMS, H., SORSCHE, P., HIRSCH, D., LI, Q., AND MARTINEZ, A. Talk to me: Exploring user

interactions with the Amazon Alexa. *Journal of Librarianship and Information Science 51*, 4 (2019), 984–997.

[158] López, G., Quesada, L., and Guerrero, L. A. Alexa vs. siri vs. cortana vs. google assistant: a comparison of speech-based natural user interfaces. In *Proceedings of the International Conference on Applied Human Factors and Ergonomics* (2017), Springer, pp. 241–250.

[159] Loschky, L. C., Larson, A. M., Magliano, J. P., and Smith, T. J. What would jaws do? the tyranny of film and the relationship between gaze and higher-level narrative film comprehension. *PloS one 10*, 11 (2015), e0142474.

[160] Lucas, G. M., Gratch, J., King, A., and Morency, L.-P. It's only a computer: Virtual humans increase willingness to disclose. *Computers in Human Behavior 37* (2014), 94–100.

[161] Luh, D.-B., Li, E. C., and Kao, Y.-J. The development of a companionship scale for artificial pets. *Interacting with Computers 27*, 2 (2015), 189–201.

[162] Mabrook, R., and Singer, J. B. Virtual Reality, 360° Video, and Journalism Studies: Conceptual Approaches to Immersive Technologies. *Journalism Studies 20*, 14 (2019), 2096–2112.

[163] MacQuarrie, A., and Steed, A. Cinematic virtual reality: Evaluating the effect of display type on the viewing experience for panoramic video. In *2017 IEEE Virtual Reality (VR)* (2017), IEEE, pp. 45–54.

[164] Maharaj, N., and Haney, C. J. A qualitative investigation of the significance of companion dogs. *Western journal of nursing research 37*, 9 (2015), 1175–1193.

[165] Marx, M. S., Cohen-Mansfield, J., Regier, N. G., Dakheel-Ali, M., Srihari, A., and Thein, K. The impact of different dog-related stimuli on engagement of persons with dementia. *American Journal of Alzheimer's Disease & Other Dementias® 25*, 1 (2010), 37–45.

[166] Masai, K., Kunze, K., Sugimoto, M., and Billinghurst, M. Empathy glasses. In *Proceedings of the ACM CHI Conference Extended Abstracts on Human Factors in Computing Systems* (2016), pp. 1257–1263.

[167] Masinter, M. R. Justice department settlement gives new power to campuses over emotional support animals. *Disability Compliance for Higher Education 21*, 5 (2015), 6–7.

[168] Massé, B., Ba, S., and Horaud, R. Tracking gaze and visual focus of attention of people involved in social interaction. *IEEE transactions on pattern analysis and machine intelligence 40*, 11 (2018), 2711–2724.

[169] McNicholas, J., and Collis, G. M. Dogs as catalysts for social interactions: Robustness of the effect. *British Journal of Psychology 91*, 1 (2000), 61–70.

[170] McNicholas, J., and Collis, G. M. Children's representations of pets in their social networks. *Child: care, health and development 27*, 3 (2001), 279–294.

[171] McNicholas, J., Gilbey, A., Rennie, A., Ahmedzai, S., Dono, J.-A., and Ormerod, E. Pet ownership and human health: a brief review of evidence and issues. *Bmj 331*, 7527 (2005), 1252–1254.

[172] Melson, G. F., Kahn Jr, P. H., Beck, A. M., Friedman, B., Roberts, T., and Garrett, E. Robots as dogs?: children's interactions with the robotic dog AIBO and a live australian shepherd. In *ACM Human factors in computing systems* (2005), pp. 1649–1652.

[173] MICROSOFT. Microsoft Rocketbox Avatar Library. `https://github.com/microsoft/Microsoft-Rocketbox`. [Accessed 2021-21-11].

[174] MICROSOFT. Understanding performance for mixed reality. `https://docs.microsoft.com/en-us/windows/mixed-reality/develop/platform-capabilities-and-apis/understanding-performance-for-mixed-reality`, March 2019. [Accessed 2021-21-11].

[175] MIKLÓSI, Á. *Dog behaviour, evolution, and cognition.* oUp Oxford, 2014.

[176] MILLER, M. K., AND SUMMERS, A. A content analysis of the evolution of video game characters as represented in video game magazines. *Journal of Media Psychology 14*, 3 (2009).

[177] MILLER, M. R., JUN, H., HERRERA, F., VILLA, J. Y., WELCH, G., AND BAILENSON, J. N. Social interaction in augmented reality. *PLOS ONE 14*, 5 (2019), 1–26.

[178] MILLER, M. R., JUN, H., HERRERA, F., YU VILLA, J., WELCH, G., AND BAILENSON, J. N. Social interaction in augmented reality. *PLOS ONE 14*, 5 (2019), e0216290.

[179] MILLER, S. C., KENNEDY, C. C., DEVOE, D. C., HICKEY, M., NELSON, T., AND KOGAN, L. An examination of changes in oxytocin levels in men and women before and after interaction with a bonded dog. *Anthrozoös 22*, 1 (2009), 31–42.

[180] MIRCIOIU, C., AND ATKINSON, J. A comparison of parametric and non-parametric methods applied to a likert scale. *Pharmacy 5*, 2 (2017), 26.

[181] MOSTAJERAN, F., STEINICKE, F., ARIZA NUNEZ, O. J., GATSIOS, D., AND FOTIADIS, D. Augmented Reality for Older Adults: Exploring Acceptability of Virtual Coaches for

Home-based Balance Training in an Aging Population. In *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems* (2020), pp. 1–12.

[182] MOTOOKA, M., KENNEDY, N. L., KOIKE, H., AND YOKOYAMA, T. Effect of dog-walking on autonomic nervous activity in senior citizens. *Medical Journal of Australia 184*, 2 (2006), 60–63.

[183] NIELSEN, L. T., MØLLER, M. B., HARTMEYER, S. D., LJUNG, T. C., NILSSON, N. C., NORDAHL, R., AND SERAFIN, S. Missing the point: an exploration of how to guide users' attention during cinematic virtual reality. In *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology* (2016), pp. 229–232.

[184] NIMER, J., AND LUNDAHL, B. Animal-assisted therapy: A meta-analysis. *Anthrozoös 20*, 3 (2007), 225–238.

[185] NORMAN, G. Likert scales, levels of measurement and the "laws" of statistics. *Advances in health sciences education 15*, 5 (2010), 625–632.

[186] NOROUZI, N., BRUDER, G., BELNA, B., MUTTER, S., TURGUT, D., AND WELCH, G. A Systematic Review of the Convergence of Augmented Reality, Intelligent Virtual Agents, and the Internet of Things. In *Springer Transactions on Computational Science Computational Intelligence*. 2019, pp. 1–24.

[187] NOROUZI, N., BRUDER, G., BELNA, B., MUTTER, S., TURGUT, D., AND WELCH, G. A systematic review of the convergence of augmented reality, intelligent virtual agents, and the internet of things. In *Artificial Intelligence in IoT*. Springer, 2019, pp. 1–24.

[188] NOROUZI, N., BRUDER, G., ERICKSON, A., KIM, K., BAILENSON, J., WISNIEWSKI, P., HUGHES, C., AND WELCH, G. Virtual animals as diegetic attention guidance mechanisms

in 360-degree experiences. *IEEE Transactions on Visualization and Computer Graphics* (2021).

[189] NOROUZI, N., KIM, K., BRUDER, G., ERICKSON, A., CHOUDHARY, Z., LI, Y., AND WELCH, G. A systematic literature review of embodied augmented reality agents in head-mounted display environments. In *In Proceedings of the International Conference on Artificial Reality and Telexistence & Eurographics Symposium on Virtual Environments* (2020), p. 11.

[190] NOROUZI, N., KIM, K., HOCHREITER, J., LEE, M., DAHER, S., BRUDER, G., AND WELCH, G. A Systematic Survey of 15 Years of User Studies Published in the Intelligent Virtual Agents Conference. In *Proceedings of the 18th ACM International Conference on Intelligent Virtual Agents* (2018), pp. 17–22.

[191] NOROUZI, N., KIM, K., LEE, M., SCHUBERT, R., ERICKSON, A., BAILENSON, J., BRUDER, G., AND WELCH, G. Walking Your Virtual Dog: Analysis of Awareness and Proxemics with Simulated Support Animals in Augmented Reality. In *Proceedings of IEEE International Symposium on Mixed and Augmented Reality* (2019), pp. 253–264.

[192] NOROUZI, N., KIM, K., LEE, M., SCHUBERT, R., ERICKSON, A., BAILENSON, J., BRUDER, G., AND WELCH, G. Walking your virtual dog: Analysis of awareness and proxemics with simulated support animals in augmented reality. In *Proceedings of the IEEE International Symposium on Mixed and Augmented Reality (ISMAR), 2019* (2019), IEEE, pp. 253–264.

[193] OBAID, M., DAMIAN, I., KISTLER, F., ENDRASS, B., WAGNER, J., AND ANDRÉ, E. Cultural behaviors of virtual agents in an augmented reality environment. In *Proceedings of the International Conference on Intelligent Virtual Agents* (2012), Springer, pp. 412–418.

[194] OBAID, M., NIEWIADOMSKI, R., AND PELACHAUD, C. Perception of Spatial Relations and of Coexistence with Virtual Agents. In *Proceedings of the International Conference on Intelligent Virtual Agents*. 2011, pp. 363–369.

[195] OH, C., HERRERA, F., AND BAILENSON, J. The effects of immersion and real-world distractions on virtual social interactions. *Cyberpsychology, Behavior, and Social Networking 22*, 6 (2019), 365–372.

[196] OH, C. S., BAILENSON, J. N., AND WELCH, G. F. A systematic review of social presence: Definition, antecedents, and implications. *Frontiers in Robotics and AI 5*, 114 (2018).

[197] OKUMOTO, S., ZHAO, F., AND SAWADA, H. Tactoglove presenting tactile sensations for intuitive gestural interaction. In *Proceedings of the IEEE International Symposium on Industrial Electronics* (2012), pp. 1680–1685.

[198] ORNE, M. T. On the social psychology of the psychological experiment: With particular reference to demand characteristics and their implications. *American psychologist 17*, 11 (1962), 776.

[199] PECK, T. C., FUCHS, H., AND WHITTON, M. C. Evaluation of reorientation techniques and distractors for walking in large virtual environments. *IEEE transactions on visualization and computer graphics 15*, 3 (2009), 383–394.

[200] PENDRY, P., KUZARA, S., AND GEE, N. R. Characteristics of student–dog interaction during a meet-and-greet activity in a university-based animal visitation program. *Anthrozoös 33*, 1 (2020), 53–69.

[201] PETERS, C., LI, C., YANG, F., AVRAMOVA, V., AND SKANTZE, G. Investigating social distances between humans, virtual humans and virtual robots in mixed reality. In *Proceed-*

ings of the 17th International Conference on Autonomous Agents and Multi-Agent Systems (2018), pp. 2247–2249.

[202] PETFOODINDUSTRY. Infographic: Most of world owns pets; dogs are tops. https://www.petfoodindustry.com/articles/5845-infographic-most-of-world-owns-pets-dogs-are-tops. [Accessed 2021-21-11].

[203] PICKARD, M. D., ROSTER, C. A., AND CHEN, Y. Revealing sensitive information in personal interviews: Is self-disclosure easier with humans or avatars and under what conditions? *Computers in Human Behavior 65* (2016), 23–30.

[204] PIUMSOMBOON, T., DAY, A., ENS, B., LEE, Y., LEE, G., AND BILLINGHURST, M. Exploring enhancements for remote mixed reality collaboration. In *SIGGRAPH Asia 2017 Mobile Graphics & Interactive Applications*. 2017, pp. 1–5.

[205] POLGÁRDI, R., TOPÁL, J., CSÁNYI, V., ET AL. Intentional behaviour in dog-human communication: an experimental analysis of “showing” behaviour in the dog. *Animal cognition 3*, 3 (2000), 159–166.

[206] POLHEBER, J. P., AND MATCHOCK, R. L. The presence of a dog attenuates cortisol and heart rate in the trier social stress test compared to human friends. *Journal of behavioral medicine 37*, 5 (2014), 860–867.

[207] PURINGTON, A., TAFT, J. G., SANNON, S., BAZAROVA, N. N., AND TAYLOR, S. H. “Alexa is my new BFF” Social Roles, User Satisfaction, and Personification of the Amazon Echo. In *Proceedings of the ACM CHI Conference Extended Abstracts on Human Factors in Computing Systems* (2017), pp. 2853–2859.

[208] RANDHAVANE, T., BERA, A., KAPSASKIS, K., GRAY, K., AND MANOCHA, D. FVA: Modeling perceived friendliness of virtual agents using movement characteristics. *IEEE Transactions on Visualization and Computer Graphics 25*, 11 (2019), 3135–3145.

[209] RAYES, A., AND SALAM, S. Internet of Things (IoT) Overview. In *Internet of Things From Hype to Reality*. Springer, 2019, pp. 1–35.

[210] RAZGRIZZZ DEMON. . `https://assetstore.unity.com/packages/3d/characters/robots/robot-sphere-136226`. [Accessed 2021-21-11].

[211] RED DEER STUDIO. . `https://assetstore.unity.com/packages/3d/characters/animals/dog-golden-retriever-187111`. [Accessed 2021-21-11].

[212] REEVES, B., HANCOCK, J., ET AL. Social robots are like real people: First impressions, attributes, and stereotyping of social robots. *Technology, Mind, and Behavior 1*, 1 (2020).

[213] REINHARDT, J., HILLEN, L., AND WOLF, K. Embedding Conversational Agents into AR: Invisible or with a Realistic Human Body? In *Proceedings of the 14th International Conference on Tangible, Embedded, and Embodied Interaction* (2020), pp. 299–310.

[214] RENNER, P., AND PFEIFFER, T. Attention guiding techniques using peripheral vision and eye tracking for feedback in augmented-reality-based assistance systems. In *2017 IEEE Symposium on 3D User Interfaces (3DUI)* (2017), IEEE, pp. 186–194.

[215] RIBI, F. N., YOKOYAMA, A., AND TURNER, D. C. Comparison of children's behavior toward sony's robotic dog aibo and a real dog: a pilot study. *Anthrozoös 21*, 3 (2008), 245–256.

[216] Ritter, F. E., Schoelles, M., Klein, L. C., and Kase, S. E. Modeling the range of performance on the serial subtraction task. In *Proceedings of the International Conference on Cognitive Modeling (ICCM)* (2007), pp. 299–304.

[217] Rogo Digital LipSync. A powerful lip-syncing and facial animation tool for Unity. https://lipsync.rogodigital.com/. [Accessed 2021-21-11].

[218] Rossbach, K. A., and Wilson, J. P. Does a dog's presence make a person appear more likable?: Two studies. *Anthrozoös 5*, 1 (1992), 40–51.

[219] Rothe, S., Buschek, D., and Hussmann, H. Guidance in cinematic virtual reality-taxonomy, research status and challenges. *Multimodal Technologies and Interaction 3*, 1 (2019), 19.

[220] Rubagotti, M., Tusseyeva, I., Baltabayeva, S., Summers, D., and Sandygulova, A. Perceived safety in physical human robot interaction–a survey. *arXiv preprint arXiv:2105.14499* (2021).

[221] Rubin, C. T., and Lanyon, L. E. Limb mechanics as a function of speed and gait: a study of functional strains in the radius and tibia of horse and dog. *Journal of experimental biology 101*, 1 (1982), 187–211.

[222] Šabanović, S., Bennett, C. C., Chang, W.-L., and Huber, L. PARO robot affects diverse interaction modalities in group sensory therapy for older adults with dementia. In *Proceedings of the 13th IEEE International Conference on Rehabilitation Robotics (ICORR)* (2013), pp. 1–6.

[223] Sablin, M. V., and Khlopachev, G. A. The Earliest Ice Age Dogs: Evidence from Eliseevichi 11. *Current Anthropology 43*, 5 (2002), 795–799.

[224] Sawada, H., Jiang, C., and Takase, H. TactoGlove: Displaying Tactile Sensations in Tacto-gestural Interaction. In *Proceedings of the IEEE International Conference on Biometrics and Kansei Engineering* (2011), pp. 216–221.

[225] Schmeil, A., and Broll, W. MARA - A Mobile Augmented Reality-Based Virtual Assistant. In *Proceedings of the IEEE Virtual Reality Conference* (2007), pp. 267–270.

[226] Schmitz, A., MacQuarrie, A., Julier, S., Binetti, N., and Steed, A. Directing versus attracting attention: Exploring the effectiveness of central and peripheral cues in panoramic videos. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (2020), IEEE, pp. 63–72.

[227] Schneider, M. S., and Harley, L. P. How dogs influence the evaluation of psychotherapists. *Anthrozoös 19*, 2 (2006), 128–142.

[228] Schrepp, M., Hinderks, A., and Thomaschewski, J. Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence 4*, 6 (2017), 103–108.

[229] Segovia, K. Y., Bailenson, J. N., and Monin, B. Morality in tele-immersive environments. In *International Conference on Immersive Telecommunications* (2009), ICST (Institute for Computer Sciences, Social-Informatics and . . . , p. 17.

[230] Sephton, T. Teaching agents for wearable augmented reality systems. In *Proceedings of the 7th IEEE International Symposium on Wearable Computers* (2003), pp. 250–250.

[231] Sheikh, A., Brown, A., Watson, Z., and Evans, M. Directing attention in 360-degree video.

[232] SHI, Y., YAN, X., MA, X., LOU, Y., AND CAO, N. Designing emotional expressions of conversational states for voice assistants: Modality and engagement. In *Extended Abstracts of the ACM CHI Conference on Human Factors in Computing Systems* (2018), pp. 1–6.

[233] SHILOH, S., SOREK, G., AND TERKEL, J. Reduction of state-anxiety by petting animals in a controlled laboratory experiment. *Anxiety, stress, and coping 16*, 4 (2003), 387–395.

[234] SIAU, K., AND WANG, W. Building trust in artificial intelligence, machine learning, and robotics. *Cutter Business Technology Journal 31*, 2 (2018), 47–53.

[235] SLATER, M. Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society B: Biological Sciences 364*, 1535 (2009), 3549–3557.

[236] SLATER, M., AND SANCHEZ-VIVES, M. V. Enhancing Our Lives with Immersive Virtual Reality. *Frontiers in Robotics and AI 3*, 74 (2016), 1–47.

[237] SMITH, T. J. The attentional theory of cinematic continuity. *Projections 6*, 1 (2012), 1–27.

[238] SOURIAU, E. La structure de l'univers filmique et le vocabulaire de la filmologie. *Revue internationale de filmologie 2*, 7 (1951), 231–240.

[239] SPEICHER, M., ROSENBERG, C., DEGRAEN, D., DAIBER, F., AND KRÚGER, A. Exploring visual guidance in 360-degree videos. In *Proceedings of the 2019 ACM International Conference on Interactive Experiences for TV and Online Video* (2019), pp. 1–12.

[240] SPHERO. STEAM Education for All Ages & Stages. `https://sphero.com/`. [Accessed 2021-21-11].

[241] STEVENS, A., HERNANDEZ, J., JOHNSEN, K., DICKERSON, R., RAIJ, A., HARRISON, C., DIPIETRO, M., ALLEN, B., FERDIG, R., FOTI, S., ET AL. The use of virtual patients

to teach medical students history taking and communication skills. *The American Journal of Surgery 191*, 6 (2006), 806–811.

[242] SULLIVAN, G. M., AND FEINN, R. Using effect size—or why the p value is not enough. *Journal of graduate medical education 4*, 3 (2012), 279–282.

[243] SUNG, J., CHRISTENSEN, H. I., AND GRINTER, R. E. Robots in the wild: understanding long-term use. In *Proceedings of the 4th ACM/IEEE international conference on Human robot interaction* (2009), pp. 45–52.

[244] SWIFTO: HOW FAST SHOULD I WALK MY DOG? . `https://swifto.com/blog/how-fast-should-i-walk-my-dog`. [Accessed 2021-21-11].

[245] TAMI, G., AND GALLAGHER, A. Description of the behaviour of domestic dog (canis familiaris) by experienced and inexperienced people. *Applied Animal Behaviour Science 120*, 3-4 (2009), 159–169.

[246] TAYLOR, S. E. Social support: A review. *The handbook of health psychology 189* (2011), 214.

[247] TAYLOR, S. E., SHERMAN, D. K., KIM, H. S., JARCHO, J., TAKAGI, K., AND DUNAGAN, M. S. Culture and social support: Who seeks it and why? *Journal of personality and social psychology 87*, 3 (2004), 354.

[248] TEMPLER, D., ARIKAWA, H., CANFIELD, M., MUNSELL, K., AND TANGAN, K. Modification of the pet attitude scale. *Society & Animals 12*, 2 (2004), 137–142.

[249] THODBERG, K., SØRENSEN, L. U., VIDEBECH, P. B., POULSEN, P. H., HOUBAK, B., DAMGAARD, V., KESELER, I., EDWARDS, D., AND CHRISTENSEN, J. W. Behavioral responses of nursing home residents to visits from a person with a dog, a robot seal or atoy cat. *Anthrozoös 29*, 1 (2016), 107–121.

[250] TONG, L., JUNG, S., LI, R. C., LINDEMAN, R. W., AND REGENBRECHT, H. Action units: Exploring the use of directorial cues for effective storytelling with swivel-chair virtual reality. In *32nd Australian Conference on Human-Computer Interaction* (2020), pp. 45–54.

[251] TRIPLETT, N. The dynamogenic factors in pacemaking and competition. *The American Journal of Psychology 9*, 4 (1898), 507–533.

[252] TROTMAN, G. P., VELDHUIJZEN VAN ZANTEN, J. J., DAVIES, J., MÖLLER, C., GINTY, A. T., AND WILLIAMS, S. E. Associations between heart rate, perceived heart rate, and anxiety during acute psychological stress. *Anxiety, Stress, & Coping 32*, 6 (2019), 711–727.

[253] USOH, M., CATENA, E., ARMAN, S., AND SLATER, M. Using presence questionnaires in reality. *Presence: Teleoperators & Virtual Environments 9*, 5 (2000), 497–503.

[254] VARDOULAKIS, L. P., RING, L., BARRY, B., SIDNER, C. L., AND BICKMORE, T. Designing relational agents as long term social companions for older adults. In *Proceedings of the International Conference on Intelligent Virtual Agents* (2012), pp. 289–302.

[255] VIRÁNYI, Z., GÁCSI, M., KUBINYI, E., TOPÁL, J., BELÉNYI, B., UJFALUSSY, D., AND MIKLÓSI, Á. Comprehension of human pointing gestures in young human-reared wolves (canis lupus) and dogs (canis familiaris). *Animal cognition 11*, 3 (2008), 373.

[256] VOIT, M., AND STIEFELHAGEN, R. Deducing the visual focus of attention from head pose estimation in dynamic multi-view meeting scenarios. In *ACM International conference on Multimodal interfaces* (2008), pp. 173–180.

[257] VORMBROCK, J. K., AND GROSSBERG, J. M. Cardiovascular effects of human-pet dog interactions. *Journal of behavioral medicine 11*, 5 (1988), 509–517.

[258] WADA, K., SHIBATA, T., SAITO, T., AND TANIE, K. Effects of robot-assisted activity for elderly people and nurses at a day service center. *Proceedings of the IEEE 92*, 11 (2004), 1780–1788.

[259] WALLGRÜN, J. O., BAGHER, M. M., SAJJADI, P., AND KLIPPEL, A. A comparison of visual attention guiding approaches for 360° image-based vr tours. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (2020), IEEE, pp. 83–91.

[260] WANG, I., SMITH, J., AND RUIZ, J. Exploring virtual agents for augmented reality. In *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems* (2019), pp. 1–12.

[261] WARREN, C. When cadaver dogs pick up a scent, archaeologists find where to dig. `https://www.nytimes.com/2020/05/19/science/cadaver-dogs-archaeology.html`. [Accessed 2021-21-11].

[262] WEBER, L. Do dogs smile? the science behind the looks we get from a happy dog. `https://www.petmd.com/dog/behavior/do-dogs-smile-science-behind-looks-we-get-happy-dog`, February 2019. [Accessed 2021-21-11].

[263] WEISS, A., WURHOFER, D., AND TSCHELIGI, M. ”I love this dog”—children’s emotional attachment to the robotic dog AIBO. *International Journal of Social Robotics 1*, 3 (2009), 243–248.

[264] WEISS, E. Selecting shelter dogs for service dog training. *Journal of Applied Animal Welfare Science 5*, 1 (2002), 43–62.

[265] Welch, G., Bruder, G., Squire, P., and Schubert, R. Anticipating Widespread Augmented Reality: Insights from the 2018 AR Visioning Workshop. Tech. rep., University of Central Florida and Office of Naval Research, August 6 2019.

[266] Wells, D. L. The facilitation of social interactions by domestic dogs. *Anthrozoös 17*, 4 (2004), 340–352.

[267] Wells, D. L. The effects of animals on human health and well-being. *Journal of social issues 65*, 3 (2009), 523–543.

[268] Wienrich, C., Gross, R., Kretschmer, F., and Müller-Plath, G. Developing and proving a framework for reaction time experiments in vr to objectively measure social interaction with virtual agents. In *2018 IEEE conference on virtual reality and 3D user interfaces (VR)* (2018), IEEE, pp. 191–198.

[269] Wills, T. A. Social support and interpersonal relationships.

[270] Wood, L., Martin, K., Christian, H., Nathan, A., Lauritsen, C., Houghton, S., Kawachi, I., and McCune, S. The pet factor-companion animals as a conduit for getting to know people, friendship formation and social support. *PloS one 10*, 4 (2015), e0122085.

[271] Wrzesien, M., Burkhardt, J.-M., Botella, C., and Alcañiz, M. Evaluation of the quality of collaboration between the client and the therapist in phobia treatments. *Interacting with Computers 24*, 6 (2012), 461–471.

[272] Wynne, C. D. What is special about dog cognition? *Current Directions in Psychological Science 25*, 5 (2016), 345–350.

[273] XU, Q., AND RAGAN, E. D. Effects of character guide in immersive virtual reality stories. In *International Conference on Human-Computer Interaction* (2019), Springer, pp. 375–391.

[274] ZALAKE, M., TAVASSOLI, F., DUKE, K., GEORGE, T., MODAVE, F., NEIL, J., KRIEGER, J., AND LOK, B. Internet-based tailored virtual human health intervention to promote colorectal cancer screening: design guidelines from two user studies. *Journal on Multimodal User Interfaces 15*, 2 (2021), 147–162.

[275] ZAPSPLAT. Free Sound Effects. `https://www.zapsplat.com/`. [Accessed 2021-21-11].

[276] ZHANG, L., AND HEALEY, P. G. Human, chameleon or nodding dog? In *Proceedings of the 20th ACM International Conference on Multimodal Interaction* (2018), pp. 428–436.

[277] ZIELKE, M. A., ZAKHIDOV, D., HARDEE, G. M., PRADEEP, J., EVANS, L., LODHI, Z., ZIMMER, K., AND WARD, E. Exploring medical cyberlearning for work at the human/technology frontier with the mixed-reality emotive virtual human system platform. In *Proceedings of the 6th IEEE International Conference on Serious Games and Applications for Health* (2018), pp. 1–8.

[278] ZILCHA-MANO, S., MIKULINCER, M., AND SHAVER, P. R. An attachment perspective on human–pet relationships: Conceptualization and assessment of pet attachment orientations. *Journal of Research in Personality 45*, 4 (2011), 345–357.