Walking Your Virtual Dog: Analysis of Awareness and Proxemics with Simulated Support Animals in Augmented Reality

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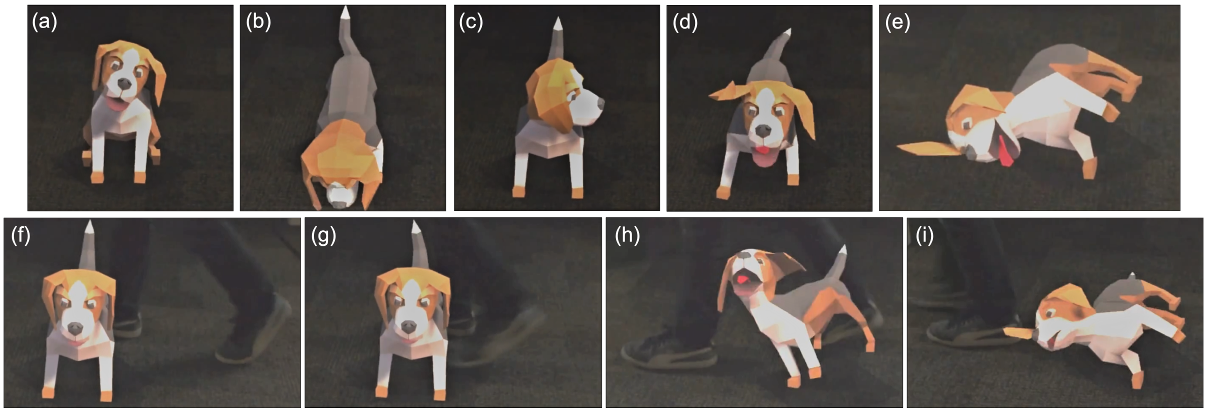

Figure 1: Photos illustrating our AR dog behavior animations: (a) idle seating, (b) sniffing, (c) idle standing, (d) barking, and (e) falling over. A sequence of photos illustrating a collision of the AR dog and a real human: (f–i) the dog is falling over when a real human walks over it. All photos were taken through a Microsoft HoloLens.

ABSTRACT

Domestic animals have a long history of enriching human lives physically and mentally by filling a variety of different roles, such as service animals, emotional support animals, companions, and pets. Despite this, technological realizations of such animals in augmented reality (AR) are largely underexplored in terms of their behavior and interactions as well as effects they might have on human users' perception or behavior. In this paper, we describe a simulated virtual companion animal, in the form of a dog, in a shared AR space. We investigated its effects on participants' perception and behavior, including locomotion related to proxemics, with respect to their AR dog and other real people in the environment. We conducted a 2×2 mixed factorial human-subject study, in which we varied (i) the AR dog's awareness and behavior with respect to other people in the physical environment and (ii) the awareness and behavior of those people with respect to the AR dog. Our results show that having an AR companion dog changes participants' locomotion behavior, proxemics, and social interaction with other people who can or can not see the AR dog. We also show that the AR dog's simulated awareness and behaviors have an impact on participants' perception, including co-presence, animalism, perceived physicality, and dog's perceived awareness of the participant and environment. We discuss our findings and present insights and implications for the realization of effective AR animal companions.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Applied computing—Law, social and behavioral sciences—Psychology

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1 INTRODUCTION

Since their domestication, animals have been leveraged by humans for a wide range of roles from service animals to social companions and emotional support animals [5, 28, 72]. An important precursor for this co-existence between humans and animals is that the human perceptual and decision-making cognitive systems are known to be receptive to social cues from certain animals and vice versa [21], which can form a bond and even lead to a shared mental model of events, behaviors, and relationships with other people, objects, and environments [24]. In particular, domestic animals such as dogs are known to form a strong social bond with their owner that manifests itself in protective behaviors or playful and excited attitudes, depending on their internal state and social cues exchanged between the animal and its owner [12].

To leverage similar benefits of human-animal interaction, the field of robotics made great advances aimed at drawing from metaphors that highlight the similarities between the robot and known animals in order to communicate affordances and facilitate a more effective, personal, and emotional interaction and co-existence [26], in various applications such as companionship [55, 65] and therapy [51].

Similar to physically manifested robotic animals, metaphors related to human-animal interaction are also being leveraged for applications in virtual reality (VR) and augmented reality (AR), where a *virtual animal* is shown via computer-generated graphics that are superimposed or integrated into a virtual or physical space [73]. Compared to robotic animals, such virtual animals lack a physical representation but have the potential to provide a more realistic, flexible, and dynamic range of visual appearances and simulated behaviors. 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. Some existing initial realizations of such virtual animals include the Playstation EyePet [57], Microsoft HoloPet [31], and Magic Leap Porg [45]. Considering the recent advances towards the convergence of AR with artificial intelligence and Internet of Things (IoT), the realization of such virtual animals can even include means of interaction with physical objects, e.g., being aware of and influencing the real environment [36, 54]. In this sense, understanding human perception and behavior with respect to virtual animals in AR is a timely and important research direction that has not yet received adequate attention, with thus far only limited insights and meaningful design guidelines for realistic and effective virtual animals as social companions and service providers [35].

In this paper, we present an exploratory human-subject study focused on improving our understanding of behaviors and characteristics of virtual animals in AR and their interaction with other people. Participants personalized their own AR dog, played and interacted with it, and walked it along a physical pathway. These activities were performed in the presence of another person in a shared physical space who was either aware of the AR dog while wearing an AR head-mounted display (HMD) or who appeared to be unaware of the AR dog. In particular, inspired by an expected important occurrence in real use situations with AR animals in close proximity with other people, we created a situation where the other person collided with the AR dog while being either *aware* or *unaware* of its existence (see Figure 1f–i). This collision then caused the dog to either (a) react in line with a physical collision with a person's foot and be knocked over or (b) exhibit behavior indicating that it is unaware that this collision even happened—i.e., show no reaction to the collision. We measured how the presence of the AR dog affected participants' proxemics, i.e., nonverbal behavior corresponding to one's physical space in response to other entities in that space, and locomotion behavior as well as their social bond with the AR dog and people in the shared physical space.

This study addresses 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 remainder of this paper is structured as follows. Section 2 covers the relevant literature in the scope of our research. We present our experimental design in Section 3 and our measures and hypotheses in Section 4. In Section 5 we present our results, and in Section 6 we discuss our main findings. Section 7 concludes the paper.

2 Related Work

In this section, we discuss related work in psychology, robotics, and VR/AR on human-animal interaction and related effects.

2.1 Emotional Support and Companion Animals

Over the years, researchers have extensively investigated the effects of having a domestic animal or pet—mostly dogs or cats—on their owner's mental and physical health. Various positive effects of domestic animals in our lives and the social bond with humans have been investigated in human–animal bond studies [77]. Most of these findings indicate benefits of such animals, such as lower increases of blood pressure under stress [3], helping with stress and providing companionship for the elderly [63], and positive affect for individuals with progressive disabilities and clinical depression [19].

In an attempt to investigate the relationships between pet ownership and human health, McNicholas et al. proposed that pets can act as "social catalysts," providing opportunities to lessen the social isolation experienced by individuals, especially older adults or people with disabilities [47]. In a review paper, Nimer and Lundahl identified four different areas where animals used for therapy have shown to be beneficial, including autism-spectrum symptoms, medical conditions, behavioral challenges, and emotional well-being [52]. Focusing specifically on children with autism-spectrum symptoms, Berry et al. discussed user studies involving children and their families and how therapy and companion dogs positively impacted various personal challenges such as anger, anxiety, as well as verbal and non-verbal behaviors [10, 15, 58].

2.2 Technological Physical Animals

With the aforementioned research on how animals can improve and affect human perception and behavior, a large body of research focused on animal-shaped robots, technological physical representations of domestic animals, and their potential benefits for human-robot interaction in the realm of service providers and social robots.

For instance, in a study by Melson et al., 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, finding that although not as much as the real dog, they still treated the Aibo in a dog-like manner [48]. Thodberg et al. 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 [69].

Regarding the behavioral patterns of human-robot animal interaction, Kerepesi et al. conducted a study looking at behavioral differences between children and adults, e.g., dog stroking behavior, when interacting with real and robotic dogs [34]. Their results indicated similar behavioral responses towards both robot and real dog such as the duration of stroking behavior of the participants. Also investigating differences between children and adults in voluntary interactions with an Aibo during a play session, Weiss et al. classified 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 [71]. These findings can provide important insights in the development and research of AR animals specially in the context of companionship.

2.3 Computer Graphics Virtual Animals

While pursuing the degree to which real animals can influence humans, computer graphics representations of animals have been developed and employed in various applications, such as entertainment and education. For instance, Miller and Summers reviewed the evolution of video game characters and found that animals are a popular choice, while occupying a wide range of different roles [49]. Animals are popular as pets and companions in games like *The Sims: Pets* [68] and *Nintendogs* [53]. They are further employed for serious games and educational applications. For instance, Chen et al. explored the effectiveness of animals in a digital classroom for 11-year old students and found increased levels of learning motivation, effort, and student performance with the animal [17].

Many researchers investigated the use of computer graphics animals for the promotion of healthy eating and physical activity in children and adolescents, using flat-panel displays and mobile phones as a way to present the animal. Byrne et al. investigated both the inclusion of virtual pets and the behavioral realism of these pets, i.e., pets that can show both happiness and sadness, finding that youths in the more realistic virtual pet condition were twice as likely to eat breakfast compared to other groups [16]. Hwsen et al. identified virtual characters as one of the contributing factors of the popularity of mobile apps and developed a healthy eating mobile app with a virtual animal giving feedback to users on their food choices [32]. Aiming to reduce childhood obesity, researchers developed a health kiosk where children could play with their virtual pets and train them while the capabilities of their pets were correlated with their owner's exercise levels, finding that children in the virtual pet condition showed higher activity levels [2, 33]. Ahn et al. investigated effects of virtual pets on children's healthy eating habits where the physical and mental health of one's pet was correlated with their fruit and vegetable consumption, finding higher consumption levels of fruits and vegetables compared to a baseline without a pet [1].

Trying to answer the question how a virtual animal's visual appearance and behavior impact human perception, researchers focused on the technical aspects of the virtual character's realistic rendering and animation, e.g., developed algorithms for motion control of quadrupeds [22, 56, 75] and focused on the rendering of realistic fur [74], while others studied the impact of visual realism on how virtual animals are perceived by users [44, 61] and how it relates to the "Uncanny Valley" phenomenon [50].

In the field of VR, Lin et al. explored concepts including affection, attachment, and motivation for playing games with virtual pets [42], and investigated the profiles of these players [43]. In a survey of 737 people, they were able to identify emotional support and real pet replacement as two major motivations for why users choose to play games with virtual pets [42]. In an attempt to propose new design opportunities for VR pet games, Lin et al. identified three player profiles of "pet-keepers," "animal teammates," and "cool hunters" based on the motivations and preferences of the players [43].

While there is evidence that virtual pets have been visualized as part of AR applications [31], we are not aware of any formal study on human-animal interaction in AR.

2.4 Proxemics and Locomotion Behavior

Proxemics is a category of nonverbal behavior related to how people manage their surrounding space in reaction to other social and/or nonsocial entities in the space. In general, people tend to keep a comfortable distance with others, which varies depending on their social relationship with and the behavior of the others as well as cultural background and situation [29]. While walking, proxemics affect one's locomotion behavior, i.e., walking speed and/or trajectories, in the space. To keep a comfortable distance with others when traversing the space, one must have an awareness of the surrounding space, predict possible threats, and adjust one's locomotion behavior [23].

As proxemics and locomotion involve one's perception of others, researchers have used them as objective measures in interactions with entities such as virtual humans. For instance, previous work revealed that people kept a larger clearance distance and a slower walking speed to virtual humans compared to non-human objects [6] or real humans [25], and that people kept more space to virtual humans exhibiting mutual awareness compared to those that do not [7]. Also, a virtual human's approaching direction [6] and invasion of personal space [40] affect proxemics and locomotion behavior.

While people often change their locomotion behavior when they are with their pets, perhaps as a protective behavior, we are unaware of any prior work exploring the effects of accompanying AR animals on proxemics and locomotion behavior.

3 Experiment

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

3.1 Participants

For this experiment, 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.

Figure 2: Snapshots of the four different appearances that participants chose for the AR dog.

3.2 Material

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

3.2.1 AR Dog's Appearance and Control

For this experiment, 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 [20, 60]; 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 2 and Figure 1(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 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 [27, 59, 67]. 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 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

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

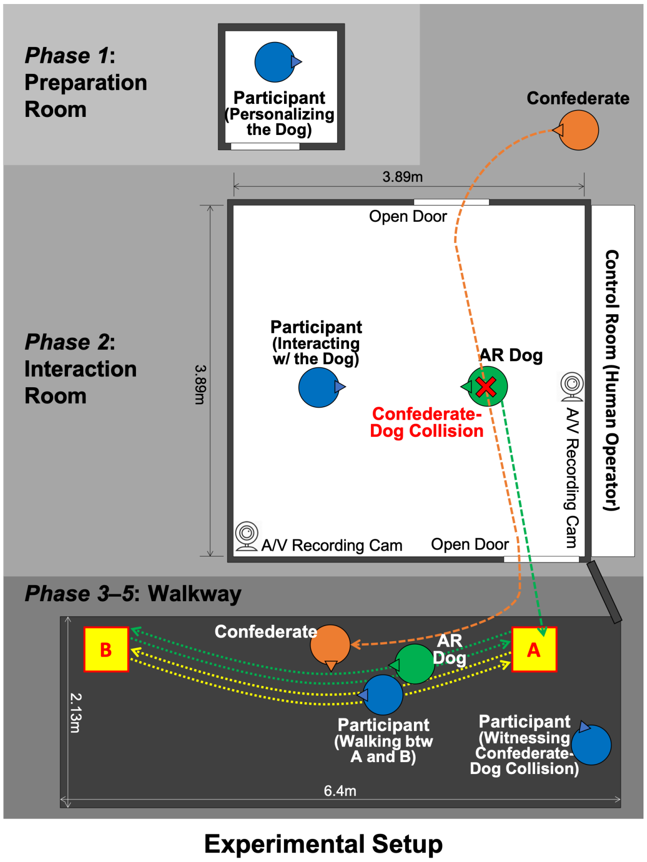


Figure 3: Top-down illustration of the laboratory space and physical setup used in the experiment.

the experimenter to trigger the different dog behaviors in real time as the participants were interacting with the AR dog.

3.2.2 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 3.3.1).

3.2.3 Physical Setup

For the experiment, we used a part of our laboratory dedicated for human-subject studies. Figure 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 4.1. We mounted two webcams for video and audio recordings on the walls of the interaction room as depicted in Figure 3, and participants were recorded throughout the experiment.

As described in Section 3.2.1, 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 3.3.2.

3.3 Method

3.3.1 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 paper, 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.

- **$C_{U,A}$**: 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.
- **$C_{A,U}$**: 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.
- **$C_{U,U}$**: 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.

3.3.2 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 2 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(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 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 wearing a HoloLens and not exhibiting awareness (see Section 3.3). 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 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 3.2.1, 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(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.

4 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.

4.1 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 3). Figure 5 illustrates our behavioral measures described below.

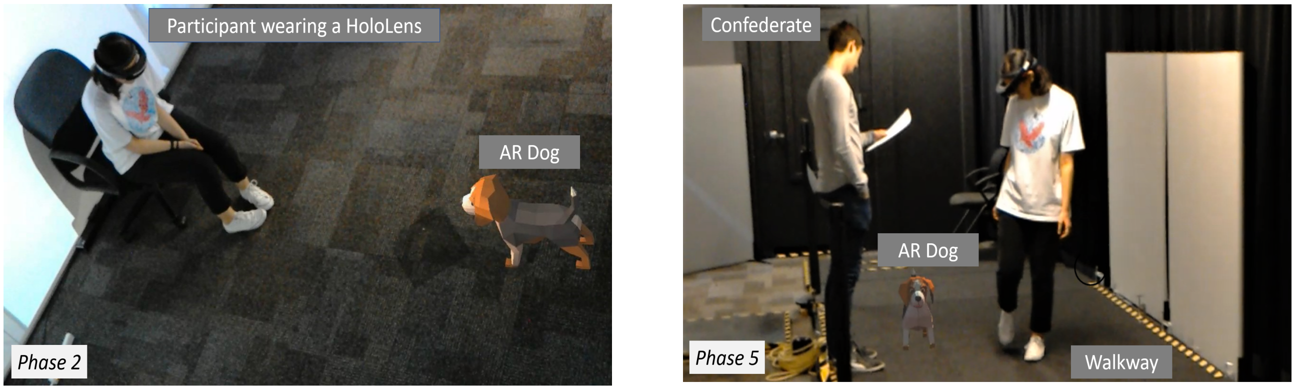
- **Passing Distance** We measured the minimum clearance distance to the confederate when participants were passing by the confederate on the walkway. This distance is known to be an indicator of participants' personal space and social presence with other entities [4].
- **Walking Speed** We computed 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*).

Table 1: Perceived Physicality questionnaire (with inverted statements for items PH2 and PH5).

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.

4.2 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



(a) Play Session (Phase 2) (b) Walking with Dog (Phase 5)

Figure 4: Experimental phases: Illustrations of (a) a person interacting with her AR dog during the play session in Phase 2 and (b) the person walking with her AR dog over the walkway in Phase 5.

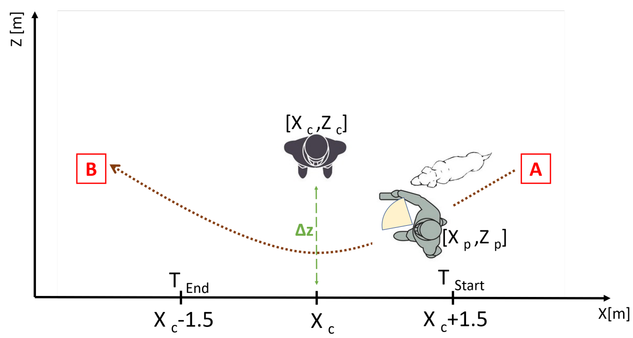


Figure 5: Illustration describing our analysis approach for our behavioral measures. To account for different participant profiles in initiation and/or stop of walking tasks we only used a range of walkway for our analysis centered ± 1.5 m around X_c (i.e., confederate's position on the X-Axis). Δz indicates 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.

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 [9]. 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. [8]. 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 1, which we modified from different sources [37, 39].
- **Affective Attraction** We used the Affective Attraction questionnaire designed by Herbst et al. [30] to assess participants' perception of the human confederates in the experiment, when they walked on the AR dog.

4.3 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 2. Figure 6 represents the notation used for our conditions. Throughout the paper, the letter **X** is used for the union of each two conditions (e.g., $C_{U,A} \cup C_{U,U} = C_{U,X}$) 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).

5 Results

In this section, we present our subjective and behavioral results. As mentioned in Section 3.1, 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.

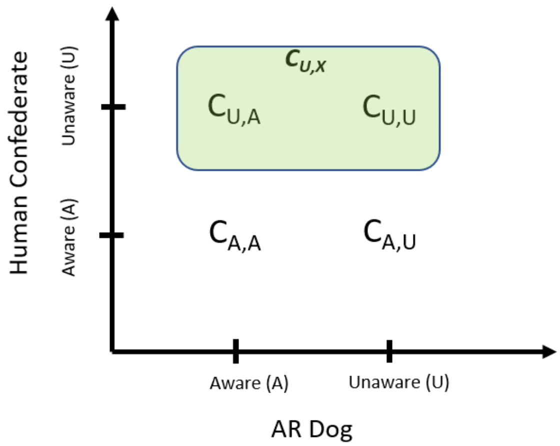


Figure 6: Summary of the experimental conditions and an example for the notations used for the analysis of our results.

Table 2: Summary of the measures with respect to our hypotheses.

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	$C_{A,X} < C_{U,X}$

5.1 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 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 [18, 66].

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.

5.1.1 Passing Distance

Figure 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.

5.1.2 Walking Speed

Figure 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 $\mathbf{C_{U,X}}$, $F(1,28) = 0.079$, $p = 0.78$.

5.1.3 Head Rotations

Figure 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 $\mathbf{C_{U,X}}$, $F(1,28) = 1.09$, $p = 0.31$.

5.1.4 Trajectory Length

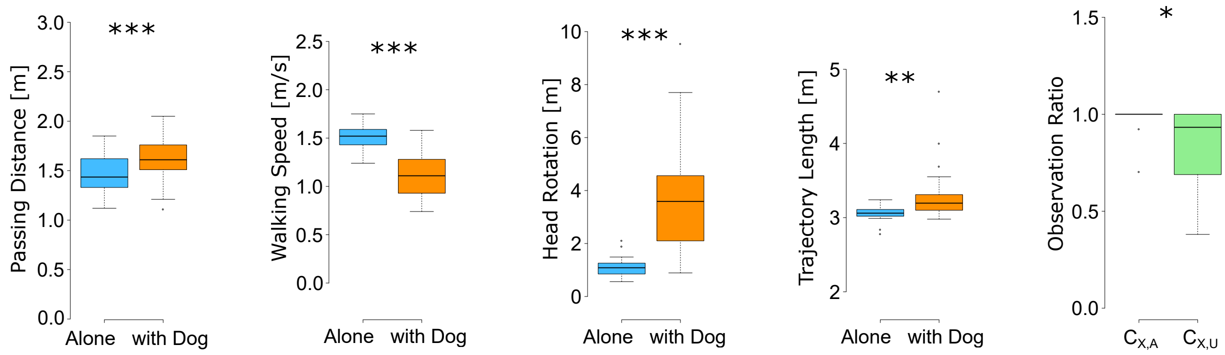
We compared the length of the path taken by participants and found a significant difference between instances of walking alone and walking with the dog, $F(1,58) = 11.96$, $\boldsymbol{p = 0.002}$, $\eta^2 = 0.23$ indicating that participants walked a longer path in each direction when walking with the 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 $\mathbf{C_{U,X}}$, $F(1,28) = 0.28$, $p = 0.6$.

5.1.5 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 7 (e) illustrates this effect. We found no significant differences between participants in groups $\mathbf{C_{A,X}}$ and $\mathbf{C_{U,X}}$, $F(1,28) = 1.34$, $p = 0.26$.

5.2 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



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

Figure 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).

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 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.

5.2.1 Co-Presence

We computed the scores for the Co-Presence questionnaire [9] 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 $\mathbf{C_{X,U}}$, $U = 55.00$, $\boldsymbol{p = 0.019}$, $r = 0.42$, shown in Figure 8(a), indicating that the dog's responsiveness to the collision increased the level of Co-Presence experienced.

5.2.2 Godspeed

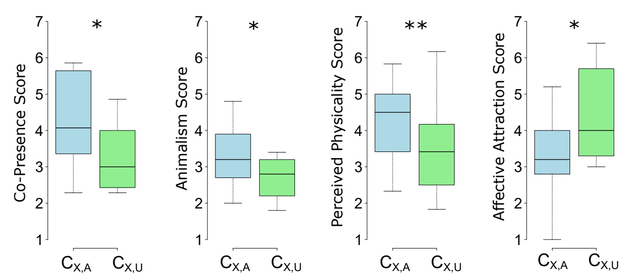
We calculated the scores for the Godspeed questionnaire [8] by computing the mean ratings for each category (Cronbach's $\alpha = 0.9$). We found a significant main effect for the AR dog's awareness and behavior in the *animalism* category between the participants in groups $\mathbf{C_{X,A}}$ and $\mathbf{C_{X,U}}$, $F(1,28) = 5.18$, $\boldsymbol{p = 0.03}$, $\eta^2 = 0.15$ shown in Figure 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.

5.2.3 Perceived Physicality

To calculate the results for the Perceived Physicality questionnaire shown in Table 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 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.

5.2.4 Affective Attraction

To calculate the results for the Affective Attraction questionnaire [30], 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 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 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).

5.3 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 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.

At the end of the experiment, we asked our participants in a short interview session about their thought process during the walking

Table 3: Different dog names chosen by participants based on the designs in Figure 2.

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			

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.

$F(1,58) = 70.17$, p=0.001, $\eta^2 = 0.23$ $F(,) =$, $p =$ ***p* =**, $\eta^2 =$

6 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.

6.1 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 5.3. 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 [46, 70]. It is important to note that these behaviors, sometimes even more pronounced, seemed to persist, as mentioned in Section 5.3, 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 [71]. 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.

6.2 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 [9], 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 [62], 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" [11]) 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 [37] or was aware of a physical blowing fan [38], or Lee et al.'s findings on the impact of a virtual human's ability to move physical objects [41]. 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 [13, 14], and the Animalism questionnaire (i.e., an adjusted category of the Godspeed questionnaire [8]) 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" [64]; 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 [76]. 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.

7 Conclusion

In this paper, 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.

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References

[1] S. J. Ahn, K. Johnsen, J. Moore, S. Brown, M. Biersmith, and C. Ball. 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):86–92, 2016.

[2] S. J. Ahn, K. Johnsen, T. Robertson, J. Moore, S. Brown, A. Marable, and A. Basu. Using virtual pets to promote physical activity in children: An application of the youth physical activity promotion model. *Journal of health communication*, 20(7):807–815, 2015.

[3] K. Allen. Are pets a healthy pleasure? the influence of pets on blood pressure. *Current Directions in Psychological Science*, 12(6):236–239, 2003.

[4] F. Argelaguet Sanz, A.-H. Olivier, G. Bruder, J. Pettre, and A. Lecuyer. Virtual Proxemics: Locomotion in the Presence of Obstacles in Large Immersive Projection Environments. In *IEEE Virtual Reality*, pp. 75–80, 2015.

[5] H. M. Audrestch, C. T. Whelan, D. Grice, L. Asher, G. C. England, and S. L. Freeman. Recognizing the value of assistance dogs in society. *Disability and health journal*, 8(4):469–474, 2015.

[6] J. N. Bailenson, J. Blascovich, A. C. Beall, and J. M. Loomis. Equilibrium Theory Revisited: Mutual Gaze and Personal Space in Virtual Environments. *Presence: Teleoperators and Virtual Environments*, 10(6):583–598, 2001.

[7] J. N. Bailenson, J. Blascovich, A. C. Beall, and J. M. Loomis. Interpersonal distance in immersive virtual environments. *Personality and Social Psychology Bulletin*, 29(7):819–833, 2003.

[8] C. Bartneck, E. Croft, and D. Kulic. Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *International Journal of Social Robotics*, 1(1):71–81, 2009.

[9] C. Basdogan, C.-H. Ho, M. A. Srinivasan, and M. Slater. An experimental study on the role of touch in shared virtual environments. *ACM Transactions on Computer-Human Interaction*, 7(4):443–460, 2000.

[10] A. Berry, M. Borgi, N. Francia, E. Alleva, and F. Cirulli. Use of assistance and therapy dogs for children with autism spectrum disorders: A critical review of the current evidence. *The journal of alternative and complementary medicine*, 19(2):73–80, 2013.
[11] F. Biocca and K. Nowak. Plugging your body into the telecommunication system: Mediated embodiment, media interfaces, and social virtual environments. *Communication technology and society*, pp. 407–447, 2001.
[12] M. Borgi and F. Cirulli. Pet face: Mechanisms underlying human-animal relationships. *Frontiers in Psychology*, 7(298):1–11, 2016.
[13] D. M. Broom. The evolution of morality. *Applied Animal Behaviour Science*, 100(1-2):20–28, 2006.
[14] D. M. Broom. Cognitive ability and awareness in domestic animals and decisions about obligations to animals. *Applied Animal Behaviour Science*, 126(1-2):1–11, 2010.
[15] K. E. Burrows, C. L. Adams, and J. Spiers. Sentinels of safety: Service dogs ensure safety and enhance freedom and well-being for families with autistic children. *Qualitative health research*, 18(12):1642–1649, 2008.
[16] S. Byrne, G. Gay, J. Pollack, A. Gonzales, D. Retelny, T. Lee, and B. Wansink. Caring for mobile phone-based virtual pets can influence youth eating behaviors. *Journal of Children and Media*, 6(1):83–99, 2012.
[17] Z.-H. Chen, C.-Y. Chou, Y.-C. Deng, and T.-W. Chan. 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):145–167, 2007.
[18] J. Cohen. *Statistical power analysis for the behavioral sciences*. Routledge, 2013.
[19] D. M. Collins, S. G. Fitzgerald, N. Sachs-Ericsson, M. Scherer, R. A. Cooper, and M. L. Boninger. Psychosocial well-being and community participation of service dog partners. *Disability and Rehabilitation: Assistive Technology*, 1(1-2):41–48, 2006.
[20] R. Coppinger and L. Coppinger. *Dogs: A Startling New Understanding of Canine Origin, Behavior & Evolution*. Scribner, 1st ed., 2001.
[21] S. Coren. *The Intelligence of Dogs: Canine Consciousness and Capabilities*. The Free Press/Macmillan, 1st ed., 1994.
[22] S. Coros, A. Karpathy, B. Jones, L. Reveret, and M. Van De Panne. Locomotion skills for simulated quadrupeds. In *ACM Transactions on Graphics*, vol. 30, p. 59, 2011.
[23] J. E. Cutting, P. M. Vishton, and P. A. Braren. How we avoid collisions with stationary and moving objects. *Psychological Review*, 102(4):627–651, 1995. doi: 10.1037/0033-295X.102.4.627
[24] Z. R. Donaldson and L. J. Young. Oxytocin, Vasopressin, and the Neurogenetics of Sociality. *Science*, 322(5903):900–904, 2008.
[25] P. W. Fink, P. S. Foo, and W. H. Warren. Obstacle avoidance during walking in real and virtual environments. *ACM Transactions on Applied Perception*, 4(1):2–es, 2007.
[26] T. Fong, I. Nourbakhsh, and K. Dautenhahn. A Survey of Socially Interactive Robots. *Robotics and Autonomous Systems*, 42(3-4):143–166, 2003.
[27] G. Goslow, H. Seeherman, C. Taylor, M. McCutchin, and N. Heglund. Electrical activity and relative length changes of dog limb muscles as a function of speed and gait. *Journal of Experimental Biology*, 94(1):15–42, 1981.
[28] C. M. Guest, G. M. Collis, and J. McNicholas. Hearing dogs: A longitudinal study of social and psychological effects on deaf and hard-of-hearing recipients. *Journal of Deaf Studies and Deaf Education*, 11(2):252–261, 2006.
[29] E. Hall. *The Hidden Dimension: man's use of space in public and in private*. 1969.
[30] K. C. Herbst, L. Gaertner, and C. A. Insko. 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):1206, 2003.
[31] HoloPet. https://www.windowscentral.com/microsoft-registers-holopet-trademark-augmented-reality-kittens-all.
[32] Y. Hswen, V. Murti, A. A. Vormawor, R. Bhattacharjee, and J. A. Naslund. Virtual avatars, gaming, and social media: Designing a mobile health app to help children choose healthier food options. *Journal of mobile technology in medicine*, 2(2):8, 2013.
[33] K. Johnsen, S. J. Ahn, J. Moore, S. Brown, T. P. Robertson, A. Marable, and A. Basu. Mixed reality virtual pets to reduce childhood obesity. *IEEE transactions on visualization and computer graphics*, 20(4):523–530, 2014.
[34] A. Kerepesi, E. Kubinyi, G. Jonsson, M. Magnusson, and A. Miklosi. Behavioural comparison of human–animal (dog) and human–robot (aibo) interactions. *Behavioural processes*, 73(1):92–99, 2006.
[35] K. Kim, M. Billinghurst, G. Bruder, H. Been-Lirn Duh, and G. F. Welch. Revisiting Trends in Augmented Reality Research: A Review of the 2nd Decade of ISMAR (2008–2017). *IEEE Transactions on Visualization and Computer Graphics*, 24:2947–2962, 2018.
[36] K. Kim, L. Boelling, S. Haesler, J. N. Bailenson, and G. B. G. F. Welch. 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 *IEEE International Symposium on Mixed and Augmented Reality*, pp. 105–114, 2018.
[37] K. Kim, G. Bruder, and G. Welch. Exploring the Effects of Observed Physicality Conflicts on RealVirtual Human Interaction in Augmented Reality. In *ACM Symposium on Virtual Reality Software and Technology*, pp. 31:1–7, 2017.
[38] K. Kim, G. Bruder, and G. F. Welch. 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*, pp. 183–190, 2018.
[39] M. Lee, G. Bruder, T. Höllerer, and G. Welch. Effects of Unaugmented Periphery and Vibrotactile Feedback on Proxemics with Virtual Humans in AR. *IEEE Transactions on Visualization and Computer Graphics*, 24(4):1525–1534, 2018.
[40] M. Lee, G. Bruder, and G. F. Welch. Exploring the effect of vibrotactile feedback through the floor on social presence in an immersive virtual environment. *Proceedings of IEEE Virtual Reality (VR)*, pp. 105–111, 2017.
[41] M. Lee, N. Norouzi, G. Bruder, P. J. Wisniewski, and G. F. Welch. The physical-virtual table: Exploring the effects of a virtual human's physical influence on social interaction. In *ACM Symposium on Virtual Reality Software and Technology*, pp. 25:1–25:11, 2018.
[42] C. Lin, T. Faas, and E. Brady. Exploring affection-oriented virtual pet game design strategies in vr attachment, motivations and expectations of users of pet games. In *IEEE International Conference on Affective Computing and Intelligent Interaction*, pp. 362–369, 2017.
[43] C. Lin, T. Faas, L. Dombrowski, and E. Brady. Beyond cute: exploring user types and design opportunities of virtual reality pet games. In *ACM Symposium on Virtual Reality Software and Technology*, p. 1, 2017.
[44] K. F. MacDorman and D. Chattopadhyay. Reducing consistency in human realism increases the uncanny valley effect; increasing category uncertainty does not. *Cognition*, 146:190–205, 2016.
[45] Magic Leap Star Wars Project Porg. . https://www.magicleap.com/experiences/star-wars-project-porg, 2019.
[46] B. Massé, S. Ba, and R. Horaud. Tracking gaze and visual focus of attention of people involved in social interaction. *IEEE transactions on pattern analysis and machine intelligence*, 40(11):2711–2724, 2018.
[47] J. McNicholas, A. Gilbey, A. Rennie, S. Ahmedzai, J.-A. Dono, and E. Ormerod. Pet ownership and human health: a brief review of evidence and issues. *Bmj*, 331(7527):1252–1254, 2005.
[48] G. F. Melson, P. H. Kahn Jr, A. M. Beck, B. Friedman, T. Roberts, and E. Garrett. Robots as dogs?: children's interactions with the robotic dog AIBO and a live australian shepherd. In *ACM Human factors in computing systems*, pp. 1649–1652, 2005.
[49] M. K. Miller and A. Summers. A content analysis of the evolution of video game characters as represented in video game magazines. *Journal of Media Psychology*, 14(3), 2009.
[50] M. Mori, K. F. MacDorman, and N. Kageki. The uncanny valley [from the field]. *IEEE Robotics & Automation Magazine*, 19(2):98–100, 2012.
[51] W. Moyle, E. Beattie, B. Draper, D. Shum, L. Thalib, C. Jones, S. O'Dwyer, and C. Mervin. Effect of an interactive therapeutic robotic

animal on engagement, mood states, agitation and psychotropic drug use in people with dementia: a cluster-randomised controlled trial protocol: Table 1. *BMJ Open*, 5(8):1–6, 2015.

[52] J. Nimer and B. Lundahl. Animal-assisted therapy: A meta-analysis. *Anthrozoös*, 20(3):225–238, 2007.

[53] Nintendogs. http://nintendogspluscats.nintendo.com/.

[54] N. Norouzi, G. Bruder, B. Belna, S. Mutter, D. Turgut, and G. Welch. 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*, pp. 1–24. 2019.

[55] Paro. Robot. http://www.parorobots.com/, 2019.

[56] X. B. Peng, G. Berseth, and M. Van de Panne. Dynamic terrain traversal skills using reinforcement learning. *ACM Transactions on Graphics*, 34(4):80, 2015.

[57] PlayStation. EyePet. https://www.playstation.com/en-us/games/eyepet-ps3/, 2019.

[58] L. A. Redefer and J. F. Goodman. Brief report: Pet-facilitated therapy with autistic children. *Journal of autism and developmental disorders*, 19(3):461–467, 1989.

[59] C. T. Rubin and L. E. Lanyon. 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):187–211, 1982.

[60] M. V. Sablin and G. A. Khlopachev. The Earliest Ice Age Dogs: Evidence from Eliseevichi 11. *Current Anthropology*, 43(5):795–799, 2002.

[61] V. Schwind, K. Leicht, S. Jäger, K. Wolf, and N. Henze. Is there an uncanny valley of virtual animals? a quantitative and qualitative investigation. *International Journal of Human-Computer Studies*, 111:49–61, 2018.

[62] K. Y. Segovia, J. N. Bailenson, and B. Monin. Morality in tele-immersive environments. In *International Conference on Immersive Telecommunications*, p. 17. ICST (Institute for Computer Sciences, Social-Informatics and , 2009.

[63] J. M. Siegel. Stressful life events and use of physician services among the elderly: the moderating role of pet ownership. *Journal of personality and social psychology*, 58(6):1081, 1990.

[64] M. Slater. Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1535):3549–3557, 2009.

[65] Sony Aibo. . http://www.sony-aibo.com/, 2019.

[66] G. M. Sullivan and R. Feinn. Using effect sizeor why the p value is not enough. *Journal of graduate medical education*, 4(3):279–282, 2012.

[67] Swifto: How fast should I walk my dog? . https://swifto.com/blog/how-fast-should-i-walk-my-dog, 2019.

[68] The Sims: Pets. https://www.ea.com/games/the-sims/the-sims-3-pets.

[69] K. Thodberg, L. U. Sørensen, P. B. Videbech, P. H. Poulsen, B. Houbak, V. Damgaard, I. Keseler, D. Edwards, and J. W. Christensen. Behavioral responses of nursing home residents to visits from a person with a dog, a robot seal or atoy cat. *Anthrozoös*, 29(1):107–121, 2016.

[70] M. Voit and R. Stiefelhagen. Deducing the visual focus of attention from head pose estimation in dynamic multi-view meeting scenarios. In *ACM International conference on Multimodal interfaces*, pp. 173–180, 2008.

[71] A. Weiss, D. Wurhofer, and M. Tscheligi. "I love this dog"childrens emotional attachment to the robotic dog AIBO. *International Journal of Social Robotics*, 1(3):243–248, 2009.

[72] L. Wood, B. Giles-Corti, and M. Bulsara. The pet connection: Pets as a conduit for social capital? *Social science & medicine*, 61(6):1159–1173, 2005.

[73] M. Wrzesien, J.-M. Burkhardt, C. Botella, and M. Alcañiz. Towards a Virtual Reality- and Augmented Reality-Mediated Therapeutic Process model: a theoretical revision of clinical issues and HCI issues. *Theoretical Issues in Ergonomics Science*, 16(2):124–153, 2015.

[74] L.-Q. Yan, C.-W. Tseng, H. W. Jensen, and R. Ramamoorthi. Physically-accurate fur reflectance: modeling, measurement and rendering. *ACM Transactions on Graphics*, 34(6):185, 2015.

[75] H. Zhang, S. Starke, T. Komura, and J. Saito. Mode-adaptive neural networks for quadruped motion control. *ACM Transactions on Graphics*, 37(4):145, 2018.

[76] S. Zilcha-Mano, M. Mikulincer, and P. R. Shaver. An attachment perspective on human–pet relationships: Conceptualization and assessment of pet attachment orientations. *Journal of Research in Personality*, 45(4):345–357, 2011.

[77] S. A. Zinn and A. M. Beck. From the Editors: The humananimal bond and domestication: Through the ages ... animals in our lives. *Animal Frontiers*, 4(3):5–6, 2014.