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Highlights

- Augmented reality (AR) allows for the investigation of virtual social support figures.
- Through a user study we investigated the supportive potentials of a virtual dog in AR.
- The virtual dog was evaluated more positively than other conditions.
- The virtual dog was perceived as more supportive than the virtual human.
- The human was perceived as more interactive than the virtual dog.

The Advantages of Virtual Dogs Over Virtual People: Using Augmented Reality to Provide Social Support in Stressful Situations

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Abstract

Past research highlights the potential for leveraging both humans and animals as social support figures in one's real life to enhance performance and reduce physiological and psychological stress. Some studies have shown that typically dogs are more effective than people. Various situational and interpersonal circumstances limit the opportunities for receiving support from actual animals in the real world introducing the need for alternative approaches. To that end, advances in augmented reality (AR) technology introduce new opportunities for realizing and investigating *virtual* dogs as social support figures. In this paper, we report on a within-subjects 3x1 (i.e., no support, virtual human, or virtual dog) experimental design study with 33 participants. We examined the effect on performance, attitude towards the task and the support figure, and stress and anxiety measured through both subjective questionnaires and heart rate data. Our mixed-methods analysis revealed that participants significantly preferred, and more positively evaluated, the virtual dog support figure than the other conditions. Emerged themes from a qualitative analysis of our participants' post-study interview responses are aligned with these findings as some of our participants mentioned feeling more comfortable with the virtual dog compared

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to the virtual human although the virtual human was deemed more interactive. We did not find significant differences between our conditions in terms of change in average heart rate; however, average heart rate significantly increased during all conditions. Our research contributes to understanding how AR virtual support dogs can potentially be used to provide social support to people in stressful situations, especially when real support figures cannot be present. We discuss the implications of our findings and share insights for future research.

Keywords: Augmented Reality, Augmented Reality Dog, Virtual Animals, Social Support

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1. Introduction

The provision of social support in stressful situations has proven to be beneficial in the reduction of stress (Allen et al., 2002; Polheber & Matchock, 2014; Brooks et al., 2018). Multiple studies have investigated the relationships between the support figure and the individual receiving the support, the behaviors of individuals providing support, the type of support figure (e.g., human, animal), and the outcomes associated with the individual receiving such support. Most studies suggest that support figures can play a positive role on these outcomes, for instance, animals or pets have been found to reduce stress and provide a sense of security due to their non-judgmental nature (Brooks et al., 2018). It is important to note that the non-judgemental nature does not mean that animals do not have the ability to judge situations and respond accordingly (Anderson et al., 2017; Cooper et al., 2003; Virányi et al., 2004), rather, it is presenting the notion that animals, and most commonly dogs, are perceived as not inducing a sense of evaluation apprehension in their human companions, resulting in their perceived non-judgmental nature (Allen et al., 2002; Vormbrock & Grossberg, 1988; Brooks et al., 2018). Additionally, some findings suggest that real animals, and more commonly dogs, can be more successful in supportive roles than real humans (Allen et al., 2002; Polheber & Matchock, 2014; Kertes et al., 2017).

Yet, the use of emotional support animals in public settings has recently become a topic of controversy (SPCA, 2018; Schoenfeld-Tacher et al., 2017; Frishberg, 2019), as some people have abused the privilege of having animals to provide a needed service, as a convenience for simply bringing their pets with them wherever they go. Meanwhile, some public spaces prohibit pets and/or animals due to allergies and increased liability (Masinter, 2015). While these complications limit beneficial human-animal interactions, they create new opportunities for exploring the potential use of augmented reality (AR) virtual support figures.

AR technology has evolved significantly over the years (Dey et al., 2018; Kim et al., 2018a), with an increasing number of research studies aimed at understanding human behavior and perception when interacting with embodied AR agents, such as virtual humans and animals (Norouzi et al., 2020). Many of the findings on embodied AR agents indicate that human behavior towards these virtual entities is similar to real life behavior. For instance, previous findings show that participants avoided a seat that had already been occupied by a virtual human in AR, in most cases even after they had taken the AR headset off (Kim et al., 2017; Miller et al., 2019), and they can reproduce real life effects of social facilitation and inhibition such as performing easier tasks better and difficult tasks worse in front of an observer (Miller et al., 2019). By using AR technology, 3D embodied agents can be rooted in the user's physical environment with opportunities to make these agents interactive and responsive to the user's needs and its physical environment. The opportunity to interact and be in the physical world is an important feature, as embodied AR agents with plausible behaviors within their physical environment have been shown to more strongly influenced users in multiple aspects such as affect, co-presence, reliability, and engagement (Lee et al., 2018; Kim et al., 2018d,b; Norouzi et al., 2019). These findings offer support for further research in realizing virtual support figures in AR and investigating their influence on human behavior and perception concerning stress and performance.

While real humans and animals have been identified as important sources of social support (Fontana et al., 1999; Allen et al., 2002; Christenfeld et al., 1997;

Brooks et al., 2018), it is less clear whether virtual humans and animals might afford the same benefits. Specifically, understanding the potential of virtual counterparts becomes more important when no real alternatives are available. A few studies in virtual reality (VR) have looked at the potential of virtual humans in the provision of support (Felnhofer et al., 2019; Kane et al., 2012; Kothgassner et al., 2019); 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, when using AR technology. Due to the novelty of research looking at social support with virtual entities, there are many open questions that need to be investigated. As a result, we prioritized the open research questions based on our assessment of their importance. First, AR technology allows the integration of virtual support figures in users' daily lives and rooted in their physical environment with opportunities to take advantage of embodied agent's plausible spatial presence (Lee et al., 2018; Kim et al., 2018d,b; Norouzi et al., 2019) and interactive verbal and nonverbal behavior borrowing from previous research (Norouzi et al., 2020). Therefore, in this work, we focused on AR technology to investigate the potentials of virtual support figures inspired by the positive findings from picture-based and virtual reality setups (Ein et al., 2019; Felnhofer et al., 2019). Second, we chose to focus specifically on virtual dogs as there have been extensive research findings on *real* dogs in supportive and therapeutic roles which are the main inspiration for our work (Beetz et al., 2012; Polheber & Matchock, 2014; Wells, 2009). Third, previous findings suggest that embodied agents presented through different mediums (e.g., robotics, AR, and VR) cannot entirely replicate the positive influences of a real humans/animals or humanoid avatars (Melson et al., 2005, 2009; Ribi et al., 2008; Kim et al., 2019a; Chesney & Lawson, 2007; Felnhofer et al., 2019), which led us to the decision of focusing on the influence of our virtual support figures in circumstances where a *real* support figure is not available, instead of comparisons with real counterparts. Last, for an initial exploration, we focused our attention on a target population that is receptive towards real dogs (i.e., no fear/general dislike of dogs) as we speculated that individuals who perceive real dogs negatively might not prefer to receive social support from a virtual dog. This decision is aligned with previous social support literature where most studies either recruited pet owners or people who did not have a negative attitude towards real dogs (Polheber & Matchock, 2014; Kertes et al., 2017; Allen et al., 2002; Ein et al., 2019) as their population. As such, we pose the following high-level research questions aimed at assessing the relative 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 (e.g., (Allen et al., 2002; Kertes et al., 2017; Polheber & Matchock, 2014)).

- **RQ1**: *Can Virtual dogs in AR provide effective social support?*
- **RQ2**: *Can virtual dogs in AR be perceived as more supporting than virtual humans in AR?*

To answer these research questions, we designed a human-subject study comparing the effects of a virtual dog support figure, a virtual human support figure, and no support figure in a cognitively stressful situation. We decided to choose our setup (i,e., task, presence of a real judge, etc.), behavior and interactivity levels of our virtual support figures, and our measures (e.g., performance (Allen et al., 2002)) in correspondence to previous social support studies (see Sections 2.1, 3.2.1, and 3.2.2) to better situate our work in relation to their findings. In our study, both the virtual dog and human were designed to exhibit supportive/relaxing behavior inspired by findings from Christenfeld et al. (1997) where real human support figures with positive expressions where shown to be more beneficial than those with neutral expressions. In order to create a stressful environment for our participants, we assigned a mental arithmetic task and followed the Trier Social Stress Test (Kirschbaum et al., 1993) with certain adaptations, where participant performance was judged by a real human panel member played by one of the researchers.

We measured participant heart rate and task performance, and collected their subjective evaluations, such as support figure evaluation and perceived stress. Our findings favor the virtual dog, as our participants evaluated it more positively compared to the other conditions, which corresponds with their increased preference for this condition over 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 (Allen et al., 2002; Polheber & Matchock, 2014; Fontana et al., 1999). 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 to its lack of judgment.

Our research makes a unique contribution of gaining a better understanding of the potential capabilities of a virtual dog in AR in the provision of social support and reduction of stress for circumstances where no real support figure is available. The remainder of this paper is structured as follows. Section 2 presents related work in the scope of this paper. Section 3 describes our experimental material and design. Section 4 presents our results, which are discussed in Section 5. Section 6 concludes the paper.

2. Related Work

In this section, we discuss previous research on social support in real and virtual settings and the roles of virtual animals related to the scope of our experiment.

2.1. Social Support in Real Settings

Social support has been defined as the experience where one feels valued and cared for in a social relationship with others (Taylor, 2011; Wills, 1991). 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.

Christenfeld et al. (1997) measured how the presence of a friend (compared to a stranger) and expression of supportive behavior (compared to neutral) can influence participants' cardiovascular reactivity during a speech-giving task, and found a lower reactivity in the presence of a friend and a stranger with supportive behavior. Fontana et al. (1999) varied the presence and type of support figures (stranger or friend) in a non-evaluative context, where support figures where given headphones during the participants' speech-giving task. Their findings indicated a lower heart rate reactivity when any of the two support figures were present compared to being alone. Allen et al. (2002) investigated the role of pets, 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 being 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 (McNicholas & Collis, 2001; McNicholas et al., 2005; Miller et al., 2009; Barker et al., 2012). Kertes et al. (2017) 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. (2010) 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 & Matchock (2014) compared the presence and type of support figure (friend, novel dog) in front of a panel of judges following the Trier Social Stress Test (Kirschbaum et al., 1993). They reported reduced salivary cortisol levels for the novel dog compared to a friend or being alone during social stress. With existing limitations in bringing pets to certain public spaces, Ein et al. (2019) studied the stress-buffering effects of pictures of support figures, such as a picture of a pet, an unfamiliar animal, or a familiar supportive person.

Their findings show that participants subjectively assessed themselves as more relaxed in the pet picture condition, although physiological measures of stress were not changed.

These findings, emphasize the stress buffering effects of real pets (more commonly dogs) and novel dogs. In this paper, we investigate whether similar effects can be observed with a virtual dog in AR and how it compares to virtual human and no support figure conditions.

2.2. Social Support in Virtual Settings

Findings from previous research (see Section 2.1) suggest that factors such as the nature of the relationship between individuals and the behavior of the support figure impact how the interaction is perceived in terms of the quality of social support. Utilizing these factors, a few researchers examined the effectiveness of virtual humans as support figures. In a virtual reality study, Kane et al. (2012) recruited pairs of romantic partners and varied the presence and attentiveness of the support figure partner during a cliff-walking task. Their results indicated that in the presence of the attentive partner compared to being alone, participants perceived the task as less stressful. Also, they felt more secure in front of the attentive partner compared to a non-attentive one, suggesting that presence of the partner alone is not enough. In a study by Kothgassner et al. (2019) participants received both verbal and non-verbal social support from either a real human, an avatar, an agent, or no support before experiencing a stressor. They found that participants in the avatar and real human support figure conditions, were less worried after both the support and task periods, while those in the agent group experienced more irritation after both sessions. Similarly, Felnhofer et al. (2019) investigated the effects of the attentive presence and agency of virtual human support figures during the preparation phase of a stressor in virtual reality, finding that those supported by the avatar experienced less tension compared to other conditions. These findings with regards to avatars being perceived as better support figures compared to agents is interesting, since self-disclosure literature with virtual humans agents suggest that people are more willing to self-disclose and are less involved with impression management in front of virtual humans (compared to real humans) as they are deemed as non-evaluative entities capable of maintaining anonymity (Kang & Gratch, 2010; Lucas et al., 2014; Pickard et al., 2016).

Because real animals, and mainly dogs, have been identified as one of the primary sources of social support, and in several cases they have been shown to provide more support than real humans (Allen et al., 2002; Polheber & Matchock, 2014; Barber & Proops, 2019; Kertes et al., 2017), in this work, we aimed to understand their ability to provide social support compared to other types of support figures (i.e., virtual human agents) and the absence of support. Unlike previous work, we chose to conduct our study using augmented reality technology to realize the potential of support figures integrated into one's physical surroundings compared to not having a support figure. Also, in our experiment we investigated the effectiveness of the support figures directly during the period the participants were involved in the task, similar to some of the previous work with real support figures (Allen et al., 2002; Fontana et al., 1999), as virtual support figures ideally can give users the opportunity of being available anywhere or anytime they are needed, unlike real support figures. It is important to note that even though the state of the art AR technology cannot support long-term interaction with such virtual support figures, the AR paradigm itself has the potential to facilitate users in real life circumstances by its integration in the users' physical environment.

2.3. Virtual Animals

Humans have been interacting with virtual animals or animal-like characters in games for decades, with the animals occupying different roles such as companions or enemies (Miller & Summers, 2009). This relationship has persisted with the evolution of technology from Tamagotchi pets[1] to popular AR games

[1] https://tamagotchi.com/

like Pokemon Go[2] and prototypes aimed at creating experiences where users can raise an AR pet (Allen et al., 2014). Some research contributions aimed at capturing users motivations for playing pet games (Chesney & Lawson, 2007; Lin et al., 2017). Chesney & Lawson (2007) conducted a survey to assess the companionship affordances of virtual pets in the Nintendogs game compared to real pets. Their findings indicated that although Nintendogs provided users with companionship it was significantly less than real pets. Additionally, Lin et al. (2017) found 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.

Virtual animals have been shown to have a motivating and encouraging role in educational and health domains for children. Chen et al. (2007) 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. (2012) investigated the effects of a mobile phone-based virtual pet game compared to a no pet condition, and the pet's range of positive/negative behavior, in the eating habits of youths. They found that participants who interacted with the virtual pet capable of both positive and negative behavior were more likely to change their eating habits positively. In several experiments, Johnsen et al. (2014) and Ahn et al. (2015, 2016) 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 (Lin et al., 2006; Dillahunt et al., 2008; Kern et al., 2019). For instance, Kern et al. (2019) created an immersive rehabilitation program using VR technology, where participants were accompanied by a virtual dog as

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

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.

Outside motivational contexts, with the potential of virtual animals as future companions, Norouzi et al. (2019) studied how a virtual dog's awareness of other people in the environment influenced participants' perceptions of the dog. Moreover, participants changed their perceptions of another person who walked through their virtual dog depending on whether the dog showed awareness of the person. Their findings suggest that in augmented reality, a virtual dog that shows awareness of the incident induced a higher sense of co-presence in participants and negatively affected their perception of the other person, regardless of that persons awareness of the virtual dog.

To our knowledge, no previous work investigates the social support affordances of virtual animals in any medium. The positive findings of many of prior studies in terms of the ability of virtual animals to provide encouragement and motivation, which are qualities attributed to real animals (Gravrok et al., 2020; Maharaj & Haney, 2015; Barber & Proops, 2019), offer promise for virtual dogs as social support figures, especially in AR where the animal can be integrated into and become a part the user's physical environment.

3. 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.

3.1. 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

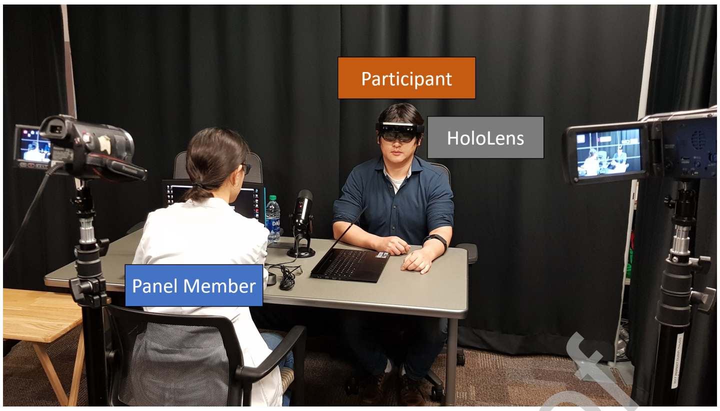


Figure 1: Annotated photo of our physical setup, showing a participant in the experiment as well as the experimenter in the lab coat, judging the performance of the participant.

that they had neither a phobia nor a general dislike of 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 (Templer et al., 2004) 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 ($M = 5.43$).

3.2. Material

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

3.2.1. 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 rigged and animated 3D character purchased from the Unity Asset Store[3]. 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 a Microsoft HoloLens 1 optical see-through head-mounted display (frame rate: 60 Hz, field of view: $\sim 30° \times 17°$, and resolution: 1268×720 per eye (Ashley, 2018; Microsoft, 2019)). The baseline and random expressions of the virtual support figures were set to be positive and calming. This choice was inspired by findings from Christenfeld et al. (1997) 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. We discuss the potential limitations of this choice in Section 5.3. The baseline expressions of the virtual support figures were set to be slightly smiling.

Additionally, every 12 seconds throughout the experiment 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 the corner of the eyes moving downward resembling a slight squint; the value for the corresponding blendshape increased from 40 to 80) or tilt its head. The changes in blendshape values were chosen based on pilot testing to ensure that the resulting facial expressions did not seem exaggerated.

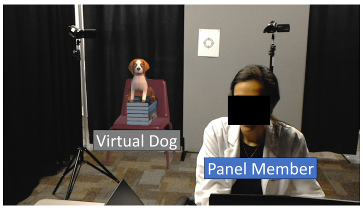
Overall, the behaviors of our virtual support figures were intentionally less interactive than behaviors such as a virtual human clapping or a virtual dog playing. This choice was inspired by previous social support literature that utilized setups where, similar to ours, the support figures were present during the study tasks (Fontana et al., 1999; Christenfeld et al., 1997) to attenuate any

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

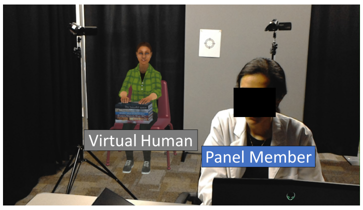
potential distraction brought about by the support figures while maintaining their positivity. To ensure that both support figures were in the participant's field of view while they were looking straight ahead (i.e., similar physical demand), we decided to place the virtual dog higher on several books 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 for the virtual dog to be perceived as anthropomorphic, which we further discuss in Section 5.3. The final state of these expressions and their behaviors are shown in Figure 3. 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.

3.2.2. Experimental Task and Setup

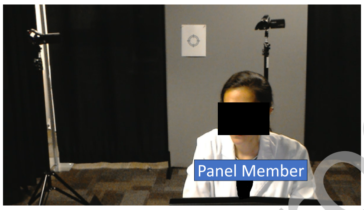
To create a stressful environment for our participants, we incorporated experimental settings similar to the previous social support studies presented in Section 2, e.g., the Trier Social Stress Test (Kirschbaum et al., 1993). *Serial Subtraction by Seven* was chosen as the stressful task, which has been shown to induce stress and increase heart rate (Ritter et al., 2007). One of three numbers (2178, 4895, and 5487) was randomly chosen as the starting number for every subject's 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 1, 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 turned 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 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



(a) Virtual Dog



(b) Virtual Human



(c) No Support

Figure 2: Participants' view while completing a stressful mental arithmetic task in the presence of an experimenter (panel member) in a lab coat, and a *support figure*: (a) virtual dog, (b) virtual human, or (c) no support figure.

experiment, and their heart rate was collected through the Wahoo app, which was synchronized with this tracker[4].

3.3. Method

We chose a within-subjects design with one factor (three levels) for our study where the conditions were (see Figure 2):

- **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

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

social support studies (Allen et al., 2002; Polheber & Matchock, 2014) 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 were 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.

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

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

Figure 3: 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.

3.3.1. 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 1. 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 starting from one of the three 4-digit numbers (2178, 4895, and 5487), which were randomly chosen for each condition. They were asked to speak the numbers out loud, to *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 could 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 would be judged by the experimenter who would measure both speed (i.e., doing more subtractions during the three-minute task) and accuracy of their subtractions. 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 to 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 starting with numbers selected from a set of five randomly ordered 4-digit numbers pre-chosen specifically for the familiarization session (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[5].

Afterward, the experimenter came back to the room, started the recording on the two cameras and the microphone, and the participants donned 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.

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

Afterward, participants performed the serial subtractions task for three minutes per condition as described in Section 3.2.2. If participants forgot a number and could not continue, the experimenter would repeat the participant's last response. After the end of each condition, with the HoloLens still on, the participants first answered a few questions about stress, anxiety, and perceived difficulty. Then they were instructed to remove the HoloLens and to answer 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.

3.3.2. Hypotheses

Our hypotheses were based on the findings from previous social support studies (Allen et al., 2002; Christenfeld et al., 1997; Fontana et al., 1999; Polheber & Matchock, 2014; Barker et al., 2010), 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 were 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.

3.3.3. Measures

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

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. (2002), which are in line with our serial subtraction task instructions given to our participants (see Section 3.3.1). Although the two approaches are related, we decided to utilize both as previous research suggested that they do not necessarily follow the same pattern (Allen et al., 2002).
    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. (1999)).

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. (2015) 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 (Kang & Wei, 2018; Taylor et al., 2004; Kim et al., 2008). Table 1 shows these questions.

- **Perceived Difficulty (H3):** To assess the participants' anticipated and actual perceived difficulty of the task, 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.

- **Perceived Stress and Anxiety (H4):** To assess the participants' anticipated and actual perceived stress and anxiety during the task, we asked

Table 1: Perceived Support questionnaire. Answers are reversed for the negative item (marked with "-").

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.

them 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.

4. 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 (Knapp, 1990; Kuzon Jr et al., 1996), 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 3 summarizes all of our significant and non-significant findings.

To analyze our post-study interview questions, we utilized a thematic analysis (Braun & Clarke, 2006) 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 to allow the themes to emerge in an inductive way. Table 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 help further explicate these themes.

Table 2: Thematic Analysis Codebook.

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 3: Summary of significant and non-significant results.

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: $W = 37.50$, $Z = -2.76$, $\boldsymbol{p = 0.006}$, $r = 0.50$

4.1. Objective Measures

Table 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.

Performance (H1): Number of Subtractions & Accuracy Rate. We did not find significant differences between any of our performance measures (see Table 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.

Mean Heart Rate (H2). Figure 5(a) shows the mean heart rate values of all participants for the three-minute relaxation period before the task and mean heart

Table 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 "(~)" 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.

Measures	Timing	None	Human	Dog
# of Subtractions (~)	During	38.00 (16.53)	37.50 (16.08)	38.50 (14.73)
Accuracy Rate (~)	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)

rate values for the three minutes during the task for each condition. As a manipulation check for our study setup, we compared participants' heart rates between each condition and the last three minutes of the relaxation 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 relaxation period (i.e., the last three minutes) and each 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 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.

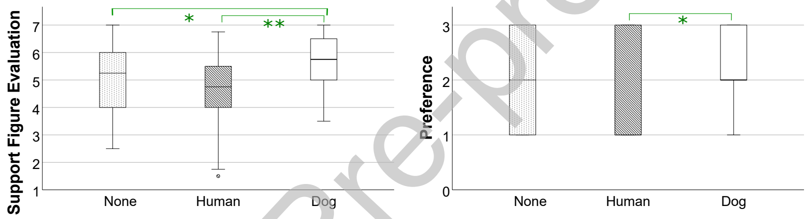
4.2. Subjective Measures

Table 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.

Support Figure Evaluation (H3). We computed average scores for questions SFE1 to SFE4 (Cronbach $\alpha = 0.8$) while reversing the negative item (see Table 1). Figure 4(a) shows the differences in participants' evaluations of the

Table 5: Summary of the means/medians (standard deviations) for the pre and post/during objective and subjective measures for the three conditions. Medians are reported for measures with data deviating from normality and are marked with "(~)." The terms *pre* and *post* are indicative of measures collected before and after the mental arithmetic task.

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)



(a) (b)

Figure 4: 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: ** ($p<0.01$), * ($p<0.05$).

support figures. We found a significant main effect of support figure type on how positively participants evaluated the support figures (see Table 3). Pairwise comparisons indicated that participants evaluated the virtual dog support figure more positively compared to the virtual human or no support figure conditions.

Preference (H3). Figure 4(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

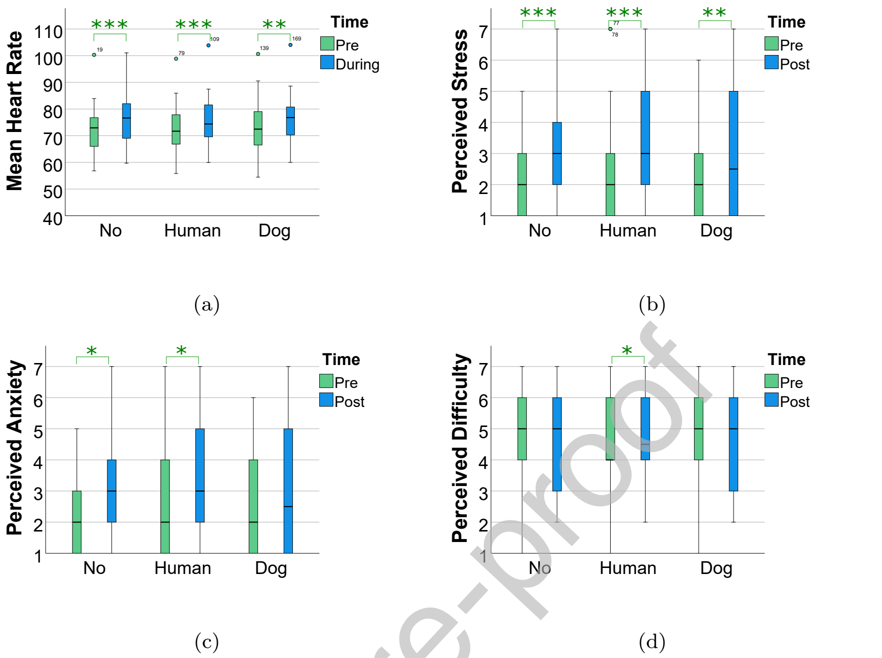


Figure 5: Box plots showing the pre and post results for (a) the mean heart rate values (in bpm) for the three conditions over the last three minutes of pre task (i.e., relaxation period) and task duration, (b) perceived stress, (c) the perceived anxiety, and (d) the perceived difficulty question. Lower scores indicate, lower mean heart rate, less stress, less anxiety, and lower perception of difficulty. Statistical significance: *** ($p<0.001$), ** ($p<0.01$), * ($p<0.05$).

preferred one, and a score of 2 to the condition in the middle.

Comparing these scores, we found a significant main effect of support figure on our participants' preference (see Table 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 3).

Perceived Difficulty (H3). Figure 5(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 3).

Perceived Stress and Anxiety (H4). Figures 5(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 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 3).

4.3. 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.

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 who 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.

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 3.2), 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 virtual human's 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.

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. 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 or changes in heart rate. In the following, we discuss our findings in more detail.

5.1. 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 (Wells, 2009), 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 relaxation period before each condition. Although our setup was inspired by previous social support studies (see Section 2.1) for inducing acute stress, based on our experimental conditions we cannot isolate the exact source of the increase in heart rate, e.g., whether somatic or cognitive (Trotman et al., 2019). We think that in the future, exploring other stressful tasks such as the cold pressor task tested by Allen et al. (2002), which does not have the cognitive aspect, may help with isolating the source of increase in heart rate.

5.2. 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 4(a)). Neither the virtual human nor the no support condition was evaluated as positively as the virtual dog. This finding supports our Hypothesis **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 (Brooks et al., 2018; Polheber & Matchock, 2014). 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 or the no support figure conditions. With research suggesting virtual agents have the ability to replicate social effects similar to real humans (Miller et al., 2019; Wienrich et al., 2018), we think that findings from the social inhibition theory with real and virtual humans (Triplett, 1898; Miller et al., 2019) 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, eight 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 (Lucas et al., 2014; Kang & Gratch, 2010; Pickard et al., 2016). 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 (Brooks et al., 2018), or whether 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 (Kertes et al., 2017; Barker et al., 2016). 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 (Allen et al., 2002; Christenfeld et al., 1997; Fontana et al., 1999). 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.

5.3. Limitations and Future Work

Our study population had certain limitations. For example, our sample size of 30, estimated through G*Power (3×1 within subjects design, $\alpha = 0.05$, Power = 0.8) (Faul et al., 2007), 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 (Kirschbaum et al., 1993) 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 choice 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 could affect the 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 & Healey (2018). 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, we did not pretest the virtual human character for the potential effects of factors such as uncanny valley, and judgmental nature on the effectiveness of its social support. However, this virtual human character was used in several previous publications (Kim et al., 2019c; Lee et al., 2018; Kim et al., 2019b; Daher et al., 2017; Lee et al., 2016; Richards et al., 2019; Kim et al., 2018c). For instance, in the work by Kim et al. (2019b), this virtual human was tested in the role of a caregiver with relatively high scores on several items regarding users' mental and physical health needs and higher than average score in the satisfaction questionnaire that included items about comfort and likeability.

Moreover, the virtual dog exhibited behaviors that sometimes humans may associate with smiling and cuteness indicated by several non-peer reviewed and one peer reviewed article (Amry et al., 2018; Llera & Buzhardt, 2021; ASPCA, 2021); however, these articles also echo that the head tilt may be a cause for health concerns and dogs' do not exhibit happiness with smiling the way humans do and the perception of a dog smiling can merely be the fact that humans anthropomorphised a dog's expression. 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 a limitation of our current work as we did not directly gauge whether the virtual dog's behaviors were perceived as anthropomorphic. 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, could shed light on the contributing characteristics of virtual dogs as support figures.

Following the guidelines of previous literature, we recruited participants who expressed neither a phobia nor a general dislike of dogs (Barber & Proops, 2019; Polheber & Matchock, 2014). 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 US (67% of households (APPA, 2021)). 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; other support figure types can be explored for this population.

Finally, 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.

6. Conclusion

In this paper, we described a human-subject study with a stressful mental arithmetic task aimed at understanding the potential of virtual dogs 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. Themes emerging 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.

Declaration of Interest

None

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References

Ahn, S. J., Johnsen, K., Moore, J., Brown, S., Biersmith, M., & Ball, C. (2016). Using virtual pets to increase fruit and vegetable consumption in children: A technology-assisted social cognitive theory approach. *Cyberpsychology, Behavior, and Social Networking*, *19*, 86–92.

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

Allen, C., Pragantha, J., & Haris, D. A. (2014). 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* (pp. 414–419). IEEE.

Allen, K., Blascovich, J., & Mendes, W. B. (2002). Cardiovascular reactivity and the presence of pets, friends, and spouses: The truth about cats and dogs. *Psychosomatic medicine*, *64*, 727–739.

Amry, M., White, C., McClellan, D., & Varakin, D. A. (2018). With this tilt, i dub you cute: Head tilt increases cuteness in puppies and adult dogs. *Journal of Vision*, *18*, 1275–1275.

Anderson, J. R., Bucher, B., Chijiiwa, H., Kuroshima, H., Takimoto, A., & Fujita, K. (2017). Third-party social evaluations of humans by monkeys and dogs. *Neuroscience & Biobehavioral Reviews*, *82*, 95–109.

APPA (2021). Pet industry market size, trends & ownership statistics. https://www.americanpetproducts.org/press_industrytrends.asp.

Ashley, J. (2018). Magic leap one vs hololens v1 comparison. https://www.imaginativeuniversal.com/blog/2018/10/08/magic-leap-one-vs-hololens-v1-comparison/.

ASPCA (2021). 7 tips on canine body language. https://www.aspcapro.org/resource/7-tips-canine-body-language.

Barber, O., & Proops, L. (2019). Low-ability secondary school students show emotional, motivational, and performance benefits when reading to a dog versus a teacher. *Anthrozoös*, *32*, 503–518.

Barker, R. T., Knisely, J. S., Barker, S. B., Cobb, R. K., & Schubert, C. M. (2012). Preliminary investigation of employee's dog presence on stress and organizational perceptions. *International Journal of Workplace Health Management*, *5*, 15–30.

Barker, S. B., Barker, R. T., McCain, N. L., & Schubert, C. M. (2016). A randomized cross-over exploratory study of the effect of visiting therapy dogs on college student stress before final exams. *Anthrozoös*, *29*, 35–46.

Barker, S. B., Knisely, J. S., McCain, N. L., Schubert, C. M., & Pandurangi, A. K. (2010). Exploratory study of stress-buffering response patterns from interaction with a therapy dog. *Anthrozoös*, *23*, 79–91.

Beetz, A., Uvnäs-Moberg, K., Julius, H., & Kotrschal, K. (2012). Psychosocial and psychophysiological effects of human-animal interactions: the possible role of oxytocin. *Frontiers in psychology*, *3*, 234.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*, 77–101.

Brooks, H. L., Rushton, K., Lovell, K., Bee, P., Walker, L., Grant, L., & Rogers, A. (2018). 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*.

Byrne, S., Gay, G., Pollack, J., Gonzales, A., Retelny, D., Lee, T., & Wansink, B. (2012). Caring for mobile phone-based virtual pets can influence youth eating behaviors. *Journal of Children and Media*, *6*, 83–99.

Chen, Z.-H., Chou, C.-Y., Deng, Y.-C., & Chan, T.-W. (2007). 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*, 145–167.

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

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

Cooper, J. J., Ashton, C., Bishop, S., West, R., Mills, D. S., & Young, R. J. (2003). Clever hounds: social cognition in the domestic dog (canis familiaris). *Applied Animal Behaviour Science*, *81*, 229–244.

Daher, S., Kim, K., Lee, M., Schubert, R., Bruder, G., Bailenson, J., & Welch, G. (2017). Effects of social priming on social presence with intelligent virtual agents. In J. Beskow, C. Peters, G. Castellano, C. O'Sullivan, I. Leite, & S. Kopp (Eds.), *Intelligent Virtual Agents: 17th International Conference, IVA 2017, Stockholm, Sweden, August 27-30, 2017, Proceedings* (pp. 87–100). Springer International Publishing volume 10498.

Dey, A., Billinghurst, M., Lindeman, R. W., & Swan, J. (2018). A systematic review of 10 years of augmented reality usability studies: 2005 to 2014. *Frontiers in Robotics and AI*, *5*, 37.

Dillahunt, T., Becker, G., Mankoff, J., & Kraut, R. (2008). Motivating environmentally sustainable behavior changes with a virtual polar bear. In *Pervasive 2008 Workshop Proceedings* (pp. 58–62). volume 8.

Ein, N., Hadad, M., Reed, M. J., & Vickers, K. (2019). Does viewing a picture of a pet during a mental arithmetic task lower stress levels? *Anthrozoös*, *32*, 519–532.

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

Felnhofer, A., Kaufmann, M., Atteneder, K., Kafka, J. X., Hlavacs, H., Beutl, L., Hennig-Fast, K., & Kothgassner, O. D. (2019). 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*, 45–51.

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

Frishberg, H. (2019). Arizona man registers swarm of bees as emotional support animals. https://nypost.com/2019/12/09/arizona-man-registers-swarm-of-bees-as-emotional-support-animals/.

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

Gravrok, J., Howell, T., Bendrups, D., & Bennett, P. (2020). 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*, *15*, 45–53.

Johnsen, K., Ahn, S. J., Moore, J., Brown, S., Robertson, T. P., Marable, A., & Basu, A. (2014). Mixed reality virtual pets to reduce childhood obesity. *IEEE Transactions on Visualization and Computer Graphics*, *20*, 523–530.

Kane, H. S., McCall, C., Collins, N. L., & Blascovich, J. (2012). Mere presence is not enough: Responsive support in a virtual world. *Journal of experimental social psychology*, *48*, 37–44.

Kang, J., & Wei, L. (2018). " 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* (pp. 106–113).

Kang, S.-H., & Gratch, J. (2010). Virtual humans elicit socially anxious interactants' verbal self-disclosure. *Computer Animation and Virtual Worlds*, *21*, 473–482.

Kern, F., Winter, C., Gall, D., Käthner, I., Pauli, P., & Latoschik, M. E. (2019). 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)* (pp. 500–509). IEEE.

Kertes, D. A., Liu, J., Hall, N. J., Hadad, N. A., Wynne, C. D., & Bhatt, S. S. (2017). Effect of pet dogs on children's perceived stress and cortisol stress response. *Social Development*, *26*, 382–401.

Kim, H. S., Sherman, D. K., & Taylor, S. E. (2008). Culture and social support. *American psychologist*, *63*, 518.

Kim, K., Billinghurst, M., Bruder, G., Duh, H. B.-L., & Welch, G. F. (2018a). 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.

Kim, K., Boelling, L., Haesler, S., Bailenson, J., Bruder, G., & Welch, G. F. (2018b). 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 *2018 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (pp. 105–114). IEEE.

Kim, K., Boelling, L., Haesler, S., Bailenson, J. N., Bruder, G., & Welch, G. F. (2018c). 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 17th IEEE International Symposium on Mixed and Augmented Reality (ISMAR 2018), Munich, Germany, October 1620, 2018*.

Kim, K., Bruder, G., & Welch, G. F. (2018d). Blowing in the wind: Increasing copresence with a virtual human via airflow influence in augmented reality. In *Proceedings of ICAT-EGVE* (pp. 183–190).

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

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

Kim, K., Norouzi, N., Losekamp, T., Bruder, G., Anderson, M., & Welch, G. (2019b). Effects of patient care assistant embodiment and computer mediation on user experience. In *2019 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)* (pp. 17–177). IEEE.

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

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

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

Kothgassner, O. D., Goreis, A., Kafka, J. X., Kaufmann, M., Atteneder, K., Beutl, L., Hennig-Fast, K., Hlavacs, H., & Felnhofer, A. (2019). 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*, 57–65.

Kuzon Jr, W. M., Urbanchek, M. G., & McCabe, S. (1996). The seven deadly sins of statistical analysis. *Annals of Plastic Surgery*, *37*, 265–272.

Lee, M., Kim, K., Daher, S., Raij, A., Schubert, R., Bailenson, J., & Welch, G. (2016). The wobbly table: Increased social presence via subtle incidental movement of a real-virtual table. In *2016 IEEE Virtual Reality (VR)* (pp. 11–17).

Lee, M., Norouzi, N., Bruder, G., Wisniewski, P. J., & Welch, G. F. (2018). 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 (VRST)* (p. 25).

Lin, C., Faas, T., & Brady, E. (2017). Exploring affection-oriented virtual pet game design strategies in vr attachment, motivations and expectations of users of pet games. In *Proceedings of the IEEE International Conference on Affective Computing and Intelligent Interaction (ACII)* (pp. 362–369).

Lin, J. J., Mamykina, L., Lindtner, S., Delajoux, G., & Strub, H. B. (2006). Fishnsteps: Encouraging physical activity with an interactive computer game. In *International conference on ubiquitous computing* (pp. 261–278). Springer.

Llera, R., & Buzhardt, L. (2021). Why dogs tilt their heads. `https://vcahospitals.com/know-your-pet/why-dogs-tilt-their-heads`.

Lucas, G. M., Gratch, J., King, A., & Morency, L.-P. (2014). Its only a computer: Virtual humans increase willingness to disclose. *Computers in Human Behavior*, *37*, 94–100.

Maharaj, N., & Haney, C. J. (2015). A qualitative investigation of the significance of companion dogs. *Western journal of nursing research*, *37*, 1175–1193.

Masinter, M. R. (2015). Justice department settlement gives new power to campuses over emotional support animals. *Disability Compliance for Higher Education*, *21*, 6–7.

McNicholas, J., & Collis, G. M. (2001). Children's representations of pets in their social networks. *Child: care, health and development*, *27*, 279–294.

McNicholas, J., Gilbey, A., Rennie, A., Ahmedzai, S., Dono, J.-A., & Ormerod, E. (2005). Pet ownership and human health: a brief review of evidence and issues. *Bmj*, *331*, 1252–1254.

Melson, G. F., Kahn, P. H., Jr, Beck, A., & Friedman, B. (2009). Robotic pets in human lives: Implications for the human–animal bond and for human relationships with personified technologies. *Journal of Social Issues*, *65*, 545–567.

Melson, G. F., Kahn Jr, P. H., Beck, A. M., Friedman, B., Roberts, T., & Garrett, E. (2005). Robots as dogs? children's interactions with the robotic dog aibo and a live australian shepherd. In *CHI'05 extended abstracts on Human factors in computing systems* (pp. 1649–1652).

Microsoft (2019). Understanding performance for mixed reality. https://docs.microsoft.com/en-us/windows/mixed-reality/develop/platform-capabilities-and-apis/understanding-performance-for-mixed-reality.

Miller, M. K., & Summers, A. (2009). A content analysis of the evolution of video game characters as represented in video game magazines. *Journal of Media Psychology*, *14*.

Miller, M. R., Jun, H., Herrera, F., Villa, J. Y., Welch, G., & Bailenson, J. N. (2019). Social interaction in augmented reality. *PLOS ONE*, *14*, 1–26.

Miller, S. C., Kennedy, C. C., DeVoe, D. C., Hickey, M., Nelson, T., & Kogan, L. (2009). An examination of changes in oxytocin levels in men and women before and after interaction with a bonded dog. *Anthrozoös*, *22*, 31–42.

Norouzi, N., Kim, K., Bruder, G., Erickson, A., Choudhary, Z., Li, Y., & Welch, G. (2020). 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* (p. 11).

Norouzi, N., Kim, K., Lee, M., Schubert, R., Erickson, A., Bailenson, J., Bruder, G., & Welch, G. (2019). 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)* (pp. 253–264).

Pickard, M. D., Roster, C. A., & Chen, Y. (2016). Revealing sensitive information in personal interviews: Is self-disclosure easier with humans or avatars and under what conditions? *Computers in Human Behavior*, *65*, 23–30.

Polheber, J. P., & Matchock, R. L. (2014). 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*, 860–867.

Ribi, F. N., Yokoyama, A., & Turner, D. C. (2008). Comparison of children's behavior toward sony's robotic dog aibo and a real dog: A pilot study. *Anthrozoös*, *21*, 245–256.

Richards, K., Mahalanobis, N., Kim, K., Schubert, R., Lee, M., Daher, S., Norouzi, N., Hochreiter, J., Bruder, G., & Welch, G. F. (2019). Analysis of peripheral vision and vibrotactile feedback during proximal search tasks with dynamic virtual entities in augmented reality. In *Proceedings of the ACM Symposium on Spatial User Interaction (SUI)* (pp. 3:1–3:9). ACM.

Ritter, F. E., Schoelles, M., Klein, L. C., & Kase, S. E. (2007). Modeling the range of performance on the serial subtraction task. In *Proceedings of the International Conference on Cognitive Modeling (ICCM)* (pp. 299–304).

Schoenfeld-Tacher, R., Hellyer, P., Cheung, L., & Kogan, L. (2017). Public perceptions of service dogs, emotional support dogs, and therapy dogs. *International journal of environmental research and public health*, *14*, 642.

SPCA (2018). Emotional support animal debate. `https://www.spcai.org/news/feature-stories/emotional-support-debate`.

Taylor, S. E. (2011). Social support: A review. *The handbook of health psychology*, *189*, 214.

Taylor, S. E., Sherman, D. K., Kim, H. S., Jarcho, J., Takagi, K., & Dunagan, M. S. (2004). Culture and social support: Who seeks it and why? *Journal of personality and social psychology*, *87*, 354.

Templer, D., Arikawa, H., Canfield, M., Munsell, K., & Tangan, K. (2004). Modification of the pet attitude scale. *Society & Animals*, *12*, 137–142.

Triplett, N. (1898). The dynamogenic factors in pacemaking and competition. *The American Journal of Psychology*, *9*, 507–533.

Trotman, G. P., Veldhuijzen van Zanten, J. J., Davies, J., Möller, C., Ginty, A. T., & Williams, S. E. (2019). Associations between heart rate, perceived heart rate, and anxiety during acute psychological stress. *Anxiety, Stress, & Coping*, *32*, 711–727.

Virányi, Z., Topál, J., Gácsi, M., Miklósi, Á., & Csányi, V. (2004). Dogs respond appropriately to cues of humans attentional focus. *Behavioural processes*, *66*, 161–172.

Vormbrock, J. K., & Grossberg, J. M. (1988). Cardiovascular effects of human-pet dog interactions. *Journal of behavioral medicine*, *11*, 509–517.

Wells, D. L. (2009). The effects of animals on human health and well-being. *Journal of social issues*, *65*, 523–543.

Wienrich, C., Gross, R., Kretschmer, F., & Müller-Plath, G. (2018). 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)* (pp. 191–198). IEEE.

Wills, T. A. (1991). *Social support and interpersonal relationships*. Sage Publications, Inc.

Zhang, L., & Healey, P. G. (2018). Human, chameleon or nodding dog? In *Proceedings of the 20th ACM International Conference on Multimodal Interaction* (pp. 428–436).

Declaration of interests

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

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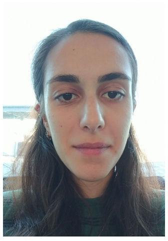

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