Co-existing With Drones: A Virtual Exploration of Proxemic Behaviours and Users' Insights on Social Drones

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Abstract

Numerous studies have investigated proxemics in the context of human-robot interactions, but little is known about whether these insights can be applied to human-drone interactions (HDI). As drones become more common in social settings, it is crucial to ensure they navigate in a socially acceptable and human-friendly way. Understanding how individuals position themselves around drones is vital to promote user well-being and drones' social acceptance. However, real-world constraints and risks associated with drones flying in close proximity to participants have limited research in this field. Virtual reality is a promising alternative for investigating HDI, as prior research suggests. This paper presents a proxemic user study (N=45) in virtual reality, examining how drone height and framing influence participants' proxemic preferences. The study also explores participants' perceptions of social drones and their vision for the future of flying robots. Our findings show that drone height significantly impacts participants' preferred interpersonal distance, while framing had no significant effect. Thoughts on how participants envision social drones (e.g., interaction, design, applications) reveal interpersonal differences but also shows overall consistency over time. While the study demonstrates the value of using virtual reality for HDI experiments, further research is necessary to determine the generalizability of our findings to real-world HDI scenarios.

Keywords: Proxemic, Human-Drone Interaction, Social Drone, Framing, Virtual Reality

1 Introduction

The increasing ease of use, affordability, and safety of drones has led to a rise in the number of drone practitioners, with a reported 10.2% increase in recreational registration to the Federal Aviation Administration (FAA) between 2020 and 2021 [3]. Additionally, aerial robots have also been utilized in various professional fields including construction [5, 57], law enforcement [33], firefighting [7, 50], delivery [37], and more. Therefore, it is reasonable to anticipate that interacting with drones on a daily basis could soon become commonplace for many individuals. As autonomous entities are expected to operate in social and inhabited environments, it is essential to ensure that their design does not pose a threat to the well-being of others. Baytas et al. [13] define social drones as autonomous drones operating in inhabited environments such as homes and cities. In their analysis of the literature around social drones, they identified six drone design concerns and six human-centered concerns, including the issue of proxemics. As drones will operate in social settings, they need to navigate in a socially acceptable and harmless way. Numerous studies have investigated proxemics in the context of human-robot interactions, but little is known about whether these insights can be applied to human-drone interactions (HDI). Flying robots offer a novel interaction paradigm and early works suggest that findings from HRI with ground-dwelling robots do not readily or directly transfer to Human—Drone Interactions (HDI).

Drones possess a unique characteristic that distinguishes them from both humans and ground/non-aerial robots, which is their ability to fly. As most casual encounters will happen while they are in the air, we investigate how the drone's flying height can affect people's proxemic behaviours. Furthermore, the relative freshness of this technology suggests that people's perspectives can strongly shape their perceptions. We wonder whether their proxemic preferences can be altered through framing technique.

In this paper, we present a proxemic user study (N=45) in virtual reality focusing on (1) the impact of the drone's flying height and (2) the type of cover story used to introduce the drone (framing) on participants' proxemic preferences. Our findings show that drone height significantly impacts participants' preferred interpersonal distance, while framing had no significant effect in the particular context of our study. Participants' feedback offers a more nuanced understanding of the results, highlighting unmet expectations and potential bias related to their backgrounds. Additionally, collected thoughts on how participants envision social drones (e.g., interaction, design, applications) reveal many interpersonal differences but also show overall consistency over time. Results also suggest that researchers can use Virtual Reality (VR) for such experiments, although we also stress the need for further research to investigate how these findings transfer to the real world.

Contribution Statement

The present research contributes to the field of human-drone interaction (HDI) by offering new insights into users' behaviors when interacting with drones in the same space, as well as how this behavior is influenced by the flying height of the drone and the framing used to introduce it. Additionally, the study investigates users' visions for the future of social drones. These findings have practical implications for drone designers seeking to adapt the navigation path of drones for social and inhabited environments. Furthermore, the study has broader implications for companies and public services seeking to deploy drones in public spaces. The results can inform the presentation and design of drones to promote positive user perceptions and minimize potential negative reactions. The study's use of an immersive virtual environment (IVE) is an innovative approach that has the potential to pave the way for future experiments in HDI. The IVE provides a level of mundane realism, control, safety, freedom, and ecological validity that is difficult to achieve in real-world experiments.

2 Related Work

This paper is an expanded and updated version of a late-breaking work published at CHI 2022 [16]. It includes a detailed analysis of the qualitative data, updated references, and an extensive discussion of the quantitative results and the use of VR. The purpose of this full-paper version is to provide a more comprehensive understanding of the research topic and contribute to the existing literature. In particular, the qualitative analysis significantly enhances the comprehension of the quantitative results and provides deeper insights into participants' views on the future of social drones.

2.1 Proxemics

2.1.1 Proxemic Functions: *Communication, Protection, Arousal Regulation*

Edward T. Hall first introduced the term "proxemic" in his book "The Hidden Dimension" (1966) to describe the spatial relationship between humans and their environment [40]. In his framework, he identified four zones that reflect different degrees of closeness and relationship. While Hall's framework has gained widespread popularity, this paper does not limit itself to his approach. As noted by Aiello in his review of research on human spatial behavior, numerous theoretical frameworks for proxemics exist. From these models, Aiello identified three main reasons why individuals maintain a certain distance between themselves and others: **(1)** to avoid excessive arousal stimulation and stressors induced by proximity (arousal regulation function) [68]; **(2)** to retain behavioral freedom to react to potential threats (protective function) [22, 29]; and/or **(3)** to communicate the type of relationship or level of intimacy between interactants (communicative function).

While the communicative function is limited in explaining proxemic behaviors around robots, particularly with drones that lack anthropomorphic features and may not be perceived as social entities by users, the three functions identified by Aiello provide a useful framework for interpreting the results. As proposed by Leichtmann et. al in a meta-analysis of proxemics in human-robot interaction [55], we will adopt these three functions to guide our interpretation of the results.

2.1.2 Human-Drone Proxemics

To date, researchers have explored various aspects of human-drone interaction (HDI) related to proxemics such as how drones should approach people [48, 75], the distance at which people feel comfortable around drones, and the factors that impact this distance [30, 31, 41, 58, 76]. Additionally, researchers have investigated how HDI differs from ground robot interaction [2] and have explored interaction methods that rely on close proximity [1, 8, 21, 59]. In particular, Duncan and colleagues as well as Han and colleagues examined the impact of a drone's altitude on the preferred distance, but found no significant effect when comparing high (2.13m) versus low (1.52m) hovering heights [30] or above the head (2.6m) versus eye level (1.7m) drone [41], respectively. Although they did not observe any effect of drone height on comfortable distance, their methods of ensuring safety during the experiments raise questions about the ecological validity of their results.

Indeed, research within this field has been hindered by the constraints of reality and the risks associated with drones flying in close proximity to people. As a result, researchers have had to resort to using techniques such as a transparent safety wall [41], fixing the drone's position [30, 76], using a fake drone [23], or limiting the minimum distance between a drone and a human [2, 30, 41] to investigate proxemic preferences.

Our belief is that explicitly controlling and limiting the settings may impact how participants perceive the situation (such as their perception of threat) and their ability to exhibit natural behaviors, potentially leading to biased proxemic observations. To address these concerns, we have opted to explore the use of virtual reality (VR) as a testbed for HDI proxemic studies. By doing so, we hope to provide a controlled and safe environment that enables us to investigate HDI proxemics with a high degree of ecological validity.

2.2 VR as a Methodological Tool

The process of distancing from one another relies on the perception and interpretation of sensory inputs, which can be affected by VR. Research has shown that certain proxemic factors, including distance perception [47, 52, 64], motor skills [6, 35], and perception of threat [27, 39, 61] can be impacted by VR. However, it has also been found that IVEs can have ecological validity in specific situations, as demonstrated in studies such as [28, 35, 67]. In addition to addressing the real-world challenges outlined in Section 2.1.2, VR has the potential to eliminate the trade-off between mundane realism and experimental control, target a more representative population, and reduce the difficulty of replicating studies [14]. Immersive virtual environments (IVEs) have been employed effectively in studies involving human-human interactions [14, 45, 54, 70], as well as human-robot proxemics research [71]. Additionally, IVEs have been used to assess the appearance of innovative drones [20, 49]. VR has been classified as the second-best method in terms of realism, behind the collocated flight, by Wojciechowska et al. [75], and it is considered safe and reproducible. In spite of its inherent safety, a recent comparative study discovered that threat perception results during a drone's approach were similar in both real and virtual environments [17]. There have been several recent studies that have emphasized the significant potential of conducting VR experiments remotely [62, 63]. While the degree to which VR findings can be applied to real-world settings is uncertain, there is potential for VR to serve as a valuable alternative to conventional methods for exploring HDI proxemics, especially given its growing popularity and affordability. Further research in this direction may shed light on the extent to which VR results can be translated to real-world scenarios.

2.3 Framing

2.3.1 Theoretical Background

Apart from investigating the impact of drone's height on participants' proxemic behavior, we also examined the influence of framing on their behavior around the drone. Frames are structures that can increase or decrease the relevance of different aspects of a situation [12]. The process of creating a frame, known as framing, involves the selection and emphasis of specific information [34]. For example, when communicating about a topic, such as a situation, object, or person, choosing to highlight or omit particular information can shape how it is perceived. The framing process can be influenced by existing individual frames, as highlighted by [72]. This means that hidden information can be brought to the forefront, while highlighted elements may be minimized, and a discrepancy between the individual's own frames and the produced frames can lead to resistance to the framing [34]. Ultimately, the framing effect can be negated or even have the opposite effect [12]. Furthermore, produced frames are more likely to be resistant when they are presented to individuals with a medium-level knowledge of the topic [53].

2.3.2 Framing for HDI

Therefore, it is crucial to investigate how framing affects the way people interact with drones, especially during the early stage of human-drone interaction (HDI), in order to ensure their successful integration into society. Currently, only a small fraction of people have had many experiences with drones, and the general frame that most people hold about drones is characterized by its fragility, instability, and unpredictability. Additionally, people with limited knowledge are more susceptible to the impact of new information (or frames) [53]. As a result, a person who has only heard about drones through news reports of accidents is likely to be wary of their potential dangers when encountering a drone for the first time.

Studies have repeatedly demonstrated the use of framing effects to manipulate people's initial reactions to robots, including influencing perceptions of their social or human-like qualities [24, 25, 44, 51]. By highlighting specific dimensions of the drone, we could potentially achieve our goals, such as reassuring an injured person during a rescue operation. Therefore, it is crucial to consider the potential biases introduced by framing in research involving drones. For instance, Chang et al. framed drones as a potential threat to privacy before assessing participants' concerns about them. As a result, the experimenters found more negative aspects of drones than positives, which contrasts with findings in prior works [23]. This suggests that framing can unintentionally bias the results of an experiment if not carefully considered. Previous studies have investigated the framing effect in some human-robot interaction research [10–12, 25, 32, 36, 69]. However, its application in HDI has received relatively little attention [42, 43]. Therefore, our work has the potential to provide valuable insights to companies, public services, and other stakeholders on how to present their drones in a way that promotes a positive user perception when deployed in public spaces.

3 Method

In this experiment, we study how the framing effect and drone's flying height influence participants' proxemic behavior in an immersive virtual environment. The process of distancing from one another is not a thoughtful and reasonable decision, but rather an automatic instinctive response in reaction to multiple sensory inputs [40]. Instead of the typical stop-approach procedure often used for Human—Drone Proxemic studies (see [30, 56]), we opted for a more natural approach to observe participants' proxemic behaviours. As seen in [9, 65], we observed participants' proxemic behavior while they performed a task that required them to pass by a flying drone in the virtual environment (see Figure 2). To precisely measure the distance between participants and the drone, we recorded their movements using the VR headset's position in the IVE. All manipulations, measures, sample size justification, and main hypotheses were pre-registered on the Open Science Framework (OSF) before data collection:

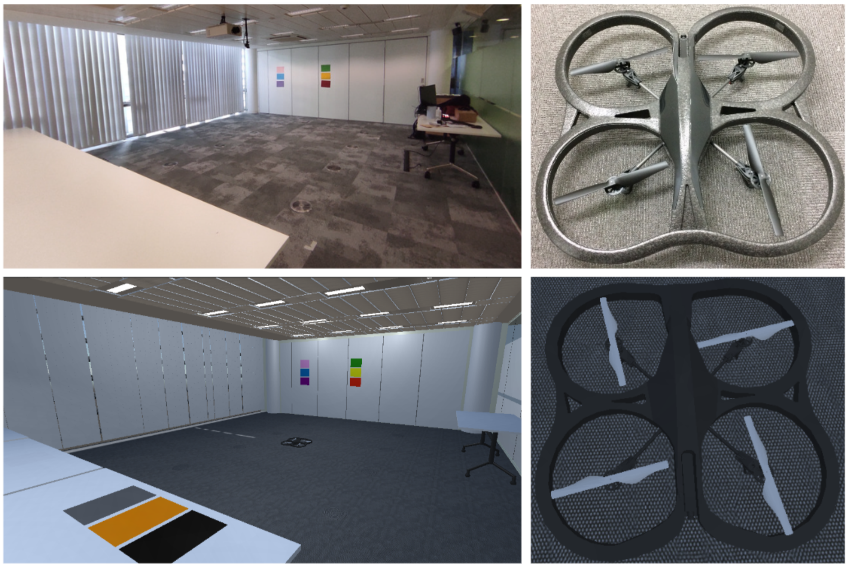

Fig. 1 The experimental room and the real Parrot AR.Drone 2.0 (top) next to their virtual replica (bottom) in Unity 3D. Participants' paths were recorded in the simulation (see Figure 2), allowing the accurate assessment of proxemic preferences around the drone, in a safe and realistic environment.

https://osf.io/7a4xu. We report all manipulations and measures in the study, in line with recent proposals [38]. Additionally, the dataset generated during the study is publicly available on a dedicated GitHub repository (see [15]).

3.1 Experimental Design

The experiment follows a 2 x 3 mixed design.

The independent variable, 'Framing', is a between-participants factor and has two levels: social and technical. The participants are assigned to either the social or technical framing group, and read a different presentation about the drone before the task. To induce a social framing of the drone, the social-oriented framing text uses a pet metaphor, assigns a name to the drone, and describes social applications. Some individuals tend to perceive autonomous drones as similar to pets [21]. We chose the pet metaphor to revive this phenomenon and evoke a stronger emotional connection compared to perceiving the drone as a mere object. Additionally, using a pet metaphor, as opposed to a human metaphor, helps mitigate potential social anxieties that can sometimes arise in human social interactions [66]. In contrast, the technical-oriented presentation is purely descriptive, using technical terms only (see Appendix B) while matching the social framing text in other surface features. The participants' perception of the drone before their first encounter was evaluated through the Robot Social attribute Scale (RoSAS) [19] and post-experiment interviews.

The independent variable "flying height" is a within-participants factor and has three levels: "above the eyes" (1.95m), "eye-level" (1.5m), and "below the eyes" (1m). Previous experiments have explored various categorical levels associated with fixed drone heights such as tall, short, overhead, and eye level [30, 41, 76]. In this experiment, we defined the drone as being at eye level when it was between +/-15cm relative to the participant's eye height. The maximum height of the drone was limited to 1.95m due to the dimensions of the room. The height conditions' order has been randomized using a Latin square.

The dependent variable used as a proxemic index is the minimum distance measured between the participant and the drone for each condition. Minimum distance is a crucial indicator of personal space boundaries, which define the limits beyond which individuals may experience anxiety, discomfort, or stress. This metric is a widely accepted and standardized metric in proxemic research. Its consistent use across studies allows for meaningful comparisons and facilitates the integration of our findings with existing literature.

In contrast, average distance can be less informative in this context due to its susceptibility to task-related variations. For instance, participants may take extra time to identify a target paper or observe the drone from a distance before approaching closely. These variations can lead to higher average distance values, even when the maintained distance is actually small. Therefore, using minimum distance measures is more appropriate for accurately capturing proxemic behaviors in this study. To measure this distance, we use the position of the participant's head (as indicated by the VR headset) relative to the drone in the virtual environment. This method is similar to that used by Baileson et al. [9]. The system records the participant-drone distance at a fixed frequency of 5 Hz, which enables us to visualize the paths taken by the participants during the task (as shown in Figure 2).

After the completion of the experiment, we conducted semi-directed interviews (30-45 minutes) with the participants to gain insights into their perception of the drone during the task, the effect of the presentations, their experience in the virtual environment, and their perspective on the future of personal drones. The interview guide sheet, which includes questions posed for each theme, can be found in the appendix (see Appendix E).

We used an affinity diagram to identify and organize the themes that emerged from participants' responses in the post-experiment interviews. An affinity diagram is a method used to organize large amounts of data, such as the responses gathered in the semi-directed interviews, into meaningful themes or categories [60]. The researchers started by familiarizing themselves with the data during the transcription process. Following that, an initial inductive examination of the data was carried out, involving the assignment of codes to significant and relevant concepts. These individual ideas were documented on digital sticky notes displayed on a virtual whiteboard. Ultimately, axial coding was employed to establish categories and uncover connections among the codes.

In addition to the post-experiment interview, we used the Igroup Presence Questionnaire (IPQ) [73] to evaluate participants' level of presence. This was important because how physically present people feel in the simulation can have a significant impact on their experience [18, 27]. However, even if we try to maximize the presence, we cannot assume that it will always be effective. The degree of presence depends not only on the environment's characteristics but also on the individual's cognitive characteristics, such as their mental imagery ability [46] or personality [26].

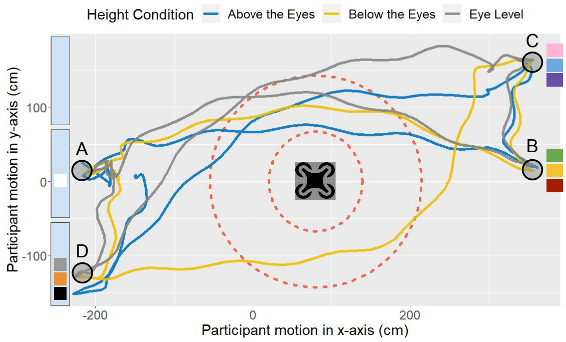

Fig. 2 Top view of a participant's path as they walk from the starting point (A) around the virtual drone to reach the colored papers (B,C,D) in the room. The sequence of colors to reach appears on the paper (white square) located on the table (blue rectangle) next to the initial position. The circular boundaries around the drone correspond to Hall's framework's intimate and personal spheres, respectively. We notice that the participant follow similar paths but maintain different distances between the conditions.

3.2 Setup and Apparatus

The virtual environment for this experiment was developed using Unity 3D and is a replica of a real-world room in the department where the study was conducted. To increase the feeling of presence, the virtual environment was intentionally created to be similar to the real-world environment [74]. Participants wore an Oculus Quest 2 mobile VR headset and could move freely within the entire room without encountering virtual walls or unexpected obstacles. The virtual participant's position was calibrated to the real one, so when they touched a virtual wall or table, they could feel the real one simultaneously. Participants had their hands free and could see them in the simulation without using controllers. The virtual drone, a Parrot AR 2.0 (see Figure 1), was controlled through a C# script with predefined animations to ensure high replicability. The experimenter used a VR controller to run the animations in response to the participant's voice commands, following a Wizard of Oz approach.

While we aimed for consistency in the drone's response time throughout the study (0.5 to 1 second), some variability was inevitable. The virtual drone's behavior was intended to replicate that of a real drone, and spatial audio was added to simulate the sound of the drone flying and landing in VR.

3.3 Participants

Before the experiment, participants filled out a questionnaire to provide their demographic information, prior experience with drones or virtual reality, adjectives they would use to describe drones, and their knowledge of drone applications (see Appendix C). A total of 45 participants (27 male, 17 female, one non-binary) mainly from scientific backgrounds such as computing science, psychology, and veterinary were recruited. The participants were between 17 to 38 years old, with various levels of experience with drones and VR, and from different origins. Experience levels with drones show a comparable distribution between the Social and Technical framing groups: in the Social group, 3 had no experience, 13 had a little, 6 had moderate, and 2 had high experience, while in the Technical group, 2 had no experience, 16 had a little, and 6 had moderate experience. The average eye height of the participants was measured using the average headset height during the simulation (M=155cm, SD=9.5cm, range=136.4cm-174.5cm). To ensure gender parity and equal group sizes, participants were randomly assigned to either the social or technical group.

3.4 Protocol

The experiment began with participants being welcomed to the experimental room, where they filled in the consent form and were informed that the room had been replicated in VR. Next, participants read a short cover story (see Appendix B) that introduced them to the drone they would be interacting with. Participants then completed the RoSAS questionnaire [19] to assess their initial perception of the drone. Next, they were given the experimental protocol to read (see Appendix D) before putting on the Oculus Quest 2 headset and being immersed in the virtual room.

Once in the virtual room, participants were instructed to ask the drone to search for their keys by saying either "Drone, look for my keys" or "Happy, look for my keys", depending on the framing. The drone then took off and a sequence of three colors appeared on the table next to the participant (see Figure 2). Participants had to memorize the sequence, touch the colored papers in the same order, and then return to the initial position. The drone was then instructed to land by saying "Happy, land" or "Drone, land." During the participants' movements, the drone remained stationary, hovering in place as if it were scanning the room while simulating occasional shakes and subtle movements, similar to what one might observe in real hovering drones. This procedure was repeated three times, with different color sequences and height conditions. The initial position, paper locations, and arrangements were designed to force participants to pass by the drone from the front and diagonally for each height condition.

After completing the experiment, participants filled out the IPQ questionnaire [73] to assess their perceived sense of presence. Finally, a semi-directed interview was conducted (30-45 minutes).

4 Results

This experiment aims to explore participants' proxemic preferences and perception of social drones by investigating the effects of flying height and framing, while also contributing to the development of virtual reality as a tool for human-drone interaction studies.

4.1 Quantitative Results

We conducted a mixed ANOVA with one between-participants factor (Framing) having two levels and one within-participant factor (Height) having three levels (2b*3w). The dependent variable was the minimum distance between the participant and the drone for each set of conditions. We checked for normality (Shapiro-Wilk test, $p > 0.05$) and homogeneity of variances (Levene's test, $p > 0.05$) and covariances (Box's test of equality of covariance matrices, $p > 0.001$). Our test also checked the sphericity assumption (Mauchly's test) and applied the Greenhouse-Geisser sphericity correction to factors violating the assumption. The results showed a significant main effect of Height ($F(2,86) = 14.948$, $p = 2.68e{-}06 < 0.0001$,

Table 1 Results of the Bonferroni-corrected multiple paired t-tests for each height condition. All pairwise comparisons are significant.

group1	group2	n1	n2	statistic	df	p	p.adj	p.adj.signif	Cohen's d
Above_Eyes	Below_Eyes	45	45	-5.1	44.0	6.8E-06	0.00002	****	-0.5956
Above_Eyes	Eye_Level	45	45	-2.9	44.0	7.0E-03	0.02000	*	-0.3095
Below_Eyes	Eye_Level	45	45	3.0	44.0	4.0E-03	0.01300	*	0.3137

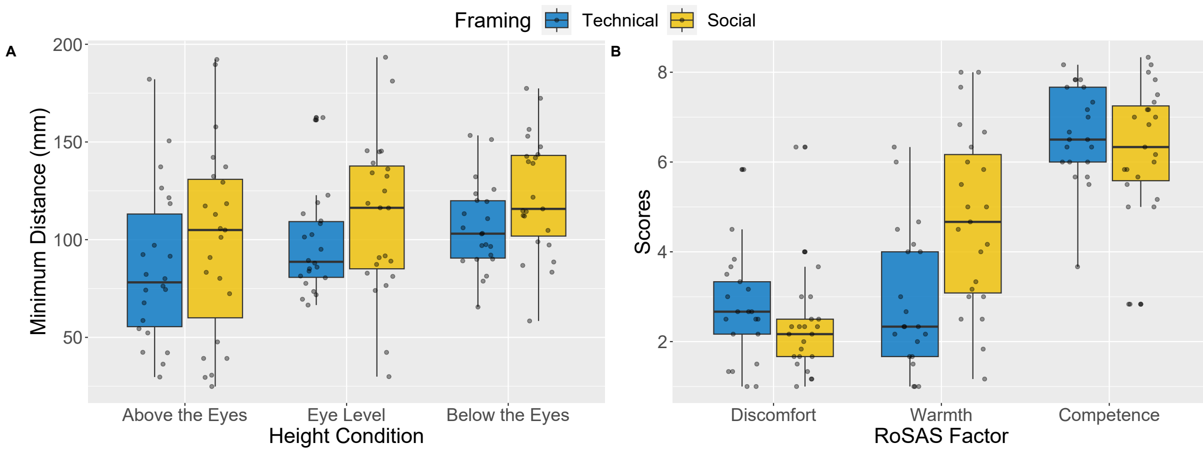

Fig. 3 **A.** Effect of the *Height* on the distance for each *Framing* condition. The boxplot indicates a significant decrease in the minimum maintained distance when comparing Above_eyes with Eye_level and Below_eye, and Eye_level with Below_eyes. **B.** Effect of the *Framing* on each RoSAS factors. We found a statistically significant higher warmth score for the *Social* condition and no significant difference for the competence and discomfort factors.

ges=0.062), but no significant effect of Framing and no interaction between the two variables.

Height

Regarding the Height factor, multiple pairwise paired t-tests with Bonferroni correction revealed significant differences between each height condition (see Table 1 and Figure 3). Participants were significantly closer to the drone in the Above Eyes condition (M=92.6cm, SD=44.8cm) compared to the Below Eyes condition (M=114.7cm, SD=27.5cm) ($p<0.0001$), the Above Eyes condition and the Eye Level condition (M=105cm, SD =34.4cm) ($p<0.05$), and the Below Eyes condition and the Eye Level condition ($p<0.05$). The findings indicate that participants tended to approach the drone when it was above their eye level and maintain a greater distance when it was below their eye level compared to the other two conditions.

Framing

In order to evaluate the impact of Framing on participants' perception of the drone prior to their initial interaction, we utilized the RoSAS [19]. This survey consists of 18 items, which are divided into three factors: warmth, competence, and discomfort. The score for each factor is calculated as the mean of the scores for its associated items. For each of these constructs, we conducted a Welch two-sample t-test, which revealed a significant difference in the Warmth ($t(41.14) = 3.4938$, $p < 0.005$, $d = 1.030259$) rating (see Figure 3). Participants' feedback during the post-experiment interview supported this result, indicating that we effectively emphasized the social aspect of the drone. We hypothesized that participants would maintain a smaller distance from "Happy" due to the drone's socially-framed appearance, however, we found the opposite to be true. On average, the social group kept a greater distance (M=111.3 cm, SD=41 cm) than the technical group (M=96.6 cm, SD=31.1 cm). This difference was not statistically significant, and as a result, we cannot generalize this finding. This observation is intriguing and warrants further exploration.

Presence

Participants' presence in the virtual environment was evaluated using the Igroup Presence Questionnaire, which includes items divided into four factors: general presence, involvement, realism, and spatial presence. The mean scores of each factor were used for analysis. Results showed that participants had a relatively high overall presence in the virtual environment, as indicated by positive scores for each dimension (see Figure 4). This suggests that the virtual environment was sufficiently convincing to elicit natural behaviors from most participants, which was also supported by feedback received during the post-experiment interview (see subsubsection 4.2.2).

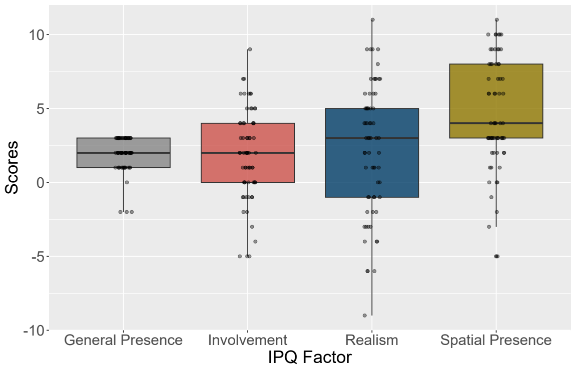

Fig. 4 Boxplot of the IPQ results for each dimension. Each mean is positive suggesting a relatively high overall presence: M(General Presence)=1.92, M(Spatial Presence)=4.74, M(Involvment)=1.86, M(Realism)=2.3

4.2 Qualitative Results

After completing the experiment, we conducted semi-structured interviews (see Appendix E) with participants to explore their perceptions of the drone during the task, the influence of the presentations, their virtual environment experience, and their expectations for the future of personal drones. We used an affinity diagram technique to identify patterns and themes in the participants' feedback [60]. We assigned a distinct code to every idea within the responses provided by each participant for each question. These distinct ideas were documented on digital sticky notes and displayed on a virtual whiteboard. In the final step, we utilized axial coding to create categories and reveal relationships among these codes. For questions where it was applicable, such as "How would you interact with it?", this approach also allowed us to quantify the size (number of occurrences among participants) of the resulting categories and visually represent these results as shown in Figure 7, located further in the paper where the interaction aspect is discussed. The specific questions from which the responses come from are provided in the figures' caption. It's important to note that due to the semi-directed nature of the interviews, not all questions from the guide sheet (Appendix E) were posed to each participant, and participants could provide multiple responses, leading to variations in response frequency.

Based on the resulting affinity diagram, we report the primary themes. Participants' responses are identified with (P+participant ID).

4.2.1 Co-existing With a Drone

We investigated participants' perspective of the drone while performing the task and gathered their opinions on both the social and technical presentations.

Where Was Your Attention Focused?

During the interviews, participants were asked about their focus during the experiment. The majority of the persons asked reported that they were primarily **focused on performing the task** at hand (n=14). For instance, one participant mentioned that they did not pay much attention to the drone as they were more concerned with completing the task correctly. (P30) said "I was more focused on doing the task. I didn't really pay much attention to the drone". Some participants **shared their attention between the task and the drone** (n=5), with some reporting that they used their listening senses to monitor the drone while visually focusing on the task. (P38) said, "Basically I think that through listening I can be more aware of if the drone is a threat to me. But visually I was more focused on finding the colors". However, a minority of participants (n=3) reported that they were **focused on the drone itself**, with one participant noting that they constantly looked at the drone because they thought it would move.

Moving Around the Drone

Participants had diverse feelings and perceptions during the phase where they had to move around the drone to reach the colors. Some participants expressed concern about **interfering with the drone's task** or damaging it. For instance, participant (P2) said, "I don't want to ruin it because it looks real", and participant (P24) was worried that they might "affect its function." In contrast, others perceived the drone as a **real object** and were careful to **avoid it to stay safe**. Participant (P35) stated that they felt fearful because of the mechanics working, and the drone was at their level. Some participants were **distracted by their task and ignored the drone**. For example, P31 tried to "just ignore it," and (P29) was focused on their task and said that "even if it was real, I think I wouldn't think too much about it." Meanwhile, others were **curious** about the drone's behavior when approached. Participant (P20) expressed their curiosity, saying, "I wanted to see if it responds to anything else," and (P8) "wanted to kind of challenge it." Additionally, some participants were motivated to avoid the drone due to the **noise** it made. (P17) said "the noise felt so real and I was like whoa no no", and (P13) moved due to "the fear induced by the loud sound of the propellers".

What Did You Think of the Drone?

The participants expressed their thoughts on the drone and suggested some changes they would like to see. They found it "**a bit big**" (P25) for an internal drone and recommended reducing its size to make navigation easier in "confined spaces" (P16). The sound of the drone was also a concern, as it was considered "**quite loud**" (P21) and similar to that of an insect (P18). Some participants suggested a "nicer noise" (P36), while others proposed making it "less noisy" (P28) to avoid distraction. However, the drone's sound was also noted to serve as a location cue. (P28) added that "you don't want it to be completely silent in case you walk into it" and (P14) said, "the good part is that with the noise [...] you are a bit more aware that it's there". To address concerns about its **unfriendly appearance**, some participants recommended adding social features such as a "smiley face" (P18) or animal-like shapes like "a butterfly or something cute" (P14). Participants also mentioned a **gap between their expectations and the actual appearance of the drone**. (P35) said, "when I was reading the description, it seemed to be, oh, it's such a sweet drone you know. [...] But it's very impersonal [...] It was very straight lines, you know, and being all black". Similarly, (P7) "didn't really get a social feeling from it" and (P31) explained, "I thought it would be smaller than that, and probably not black, then something that looks quite friendly and cute or something. So I was kind of surprised there was like a large black generic looking drone". Some suggested the use of "more warm colors" and making it "less rough" (P35). Other requested **functionalities** include indicating the direction of its sensors (P22) and automatic collision detection and avoidance (P0).

Social Expectations

During the study, two different presentations were shown to the participants. One of them was socially oriented, while the other was neutral and focused solely on presenting the technical aspects of the drone (see Appendix B). In the interviews, participants were shown the other presentation and asked if they thought their behavior or perception of the drone would have been different if they had seen that presentation instead.

Some participants (n=7) of the technical group stated that the social presentation would not make a difference for them, as they were **not sensitive to social cues** and preferred the technical presentation due to their specific **interest in technology**. (P25) said "I would be able to, you know, control my natural instincts as human and look at it objectively". Yet (P9) expressed the belief that they are part of a minority "when it comes to how interested I am in drones", and therefore preferred not to have a technical presentation because it would make the drones seem less human for others. This perspective is in line with other participants who noted a **positive perception of the social presentation** compared to the technical one. According to (P9), the social presentation is beneficial for end-users because it can improve their negative overall perception of drones. Similarly, (P29) believes that the social presentation is more positive and less intimidating, making people more open-minded about drones. (P2) suggests that the social presentation may make drones more acceptable to people who are hesitant to interact with technology. The way the drone was presented socially appears to have influenced how participants perceived the **drone's social role**. For example, (P3) suggested that naming the drone would make it feel like a pet, while (P16) thought that it could be a replacement for a deceased animal. (P5) also believed that a social presentation would give the drone more character and make it feel like a companion, rather than just an object. These social roles influenced participants' behavior towards the drone, with (P23) saying that they would have paid more attention to the drone if it had been presented socially, and (P5) indicating that they only walked around the drone but would have acknowledged it more if it had been presented as a companion. A group of participants expressed their feelings of **dissonance** between the social presentation and the actual drone. For instance, (P38) mentioned that while the social presentation made the drone seem friendly, the actual drone might still appear as a tool, which creates a discrepancy between expectation and reality. Similarly, (P18) felt that the actual drone did not match their expectations based on the social presentation, creating a significant difference that they could not explain. (P29) also mentioned that the social presentation made the drone more engaging and personable, but they did not have the same feeling when interacting with the actual drone. (P35) pointed out that the social presentation induced positive expectations and feelings, but they experienced disconnection and dissonance when interacting with the actual drone. (P35) said "If the presentation was different, like just objective and technical, I would go there without any expectation like this is going to be a drone. [...] It's funny because, since I had such a dissonance because you are inducing these feelings it's going to be something sweet. So before interacting with the drone, in my head I was not visualizing the drone itself. It was just a blank. So there was some disconnection between what I saw and what I thought I would see. So you just change this first part here. Being more technical, yeah, it's totally different. My expectations would be totally different. When I started the experiment I had like a positive expectation. How could I expect a drone to be friendly or empathetic? I could not even visualize the drone in my head." Overall, the significantly higher perceived warmth for the social presentation before interacting with the drone underscores the expectation difference between the two presentations (see Figure 3).

4.2.2 Experimenting in VR

During the interviews, we also investigated participants' feelings while navigating the virtual environment, with the aim of identifying any potential constraints of using this approach for future HDI proxemics research, gaining a deeper insight into the subjective impacts reported by participants as well as to gather ideas for improvements.

A Compelling Virtual Experience

According to participants' feedback, the virtual environment (VE) was perceived as convincing and realistic, which is consistent with the results of the presence questionnaire (see Figure 4). Specifically, the virtual replica of the room and the drone's aspect, sound, and behavior were mentioned as crucial elements for their immersion. Many participants described the VE as "realistic and accurate", such as (P3) who felt that "it felt completely real", (P7) who noticed "barely any difference", and (P31) who reported that "it's almost like you're not putting anything on" when wearing the goggles. Some participants also emphasized the importance of the drone's realism, such as (P1), who appreciated that "it looked like a drone that I'd seen before and the sound was very realistic to a drone flying and its movement". (P33) also felt that "the simulation really gave that experience of having a drone in the room", and even felt cautious with the drone's presence, despite knowing that it was only a simulation.

However, some participants also mentioned certain issues that hindered their immersion in the VE. For instance, P20 felt that the VE was "too clean", while P4 reported that "the frame rate was quite low", and P29 mentioned that "the resolution was off". These issues align with the participants' suggestions to improve the VE further (see Figure 5).

Difference With the Real World

We inquired whether participants would have acted similarly if the experiment had taken place in the physical world. The majority of those who answered would have either acted the same (n=21) or kept a greater distance (n=9). For instance, (P35) cited the noise and said, "If the drone made

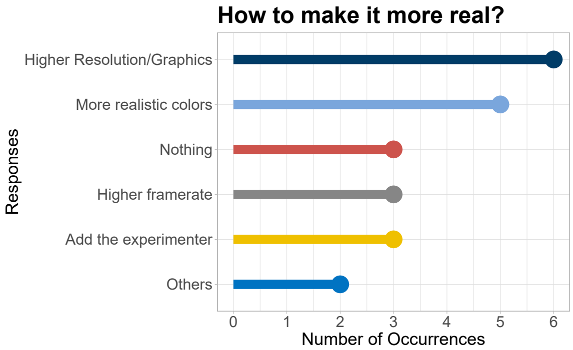

Fig. 5 Responses to the question "Compared to a real-world environment, what do you think was missing to make it more compelling?" and their frequency. Its technical performances (resolution, frame rate) and visual aspect were the principal ways of improvement.

the same noise and was just as annoying, I would behave the same way." (P7) mentioned safety, stating that "even though it was a virtual drone, I would not really go near to it. Just to be scared if it cuts my ear or something." (P18) supported this perspective by commenting, "Oh, I totally put myself in the environment, and I totally thought that if it flew towards me, I would duck. I would like run away." Interestingly, contrary feedback has been given. (P38) remarked, "I felt safe. It can't literally hurt me, but if it's a real one, I think I would want to keep a safer distance from it," and (P3) stated, "I would have probably given it more distance because I thought you know that could really harm me." These findings indicate that changes in threat perception can occur in virtual reality and may be influenced by individual factors.

4.2.3 Future of Drones

During the interviews, we prompted participants to imagine a hypothetical scenario where drones were widely used and had no technological limitations, and they themselves had a personal drone. Within this context, we asked participants to share their opinions on potential applications, methods of interaction, reasons for potential rejection, social acceptability, and how their personal drone would differ from public or company-owned drones.

Applications

As presented in Figure 6, participants predominantly mentioned using their personal drone to assist with **household tasks** such as "cleaning the house" (P31), "walking the dog" (P24), or "tidying up the room" (P9). The next most frequently reported uses were **photography**, **transporting or delivering objects**, and **surveillance**. These applications align with the existing known uses of drones as reported in the demographic questionnaire (see Appendix C). Some participants expressed a desire for the drone to be a **companion** or to accompany them while jogging ((P9) "having a drone to go with me would encourage me more."). Lastly, participants mentioned using their drone as a remote pair of eyes to **monitor specific areas** (e.g., (P4) "I want to go play basketball and I'm not sure how many people are there.", (P20) "check where there is traffic.").

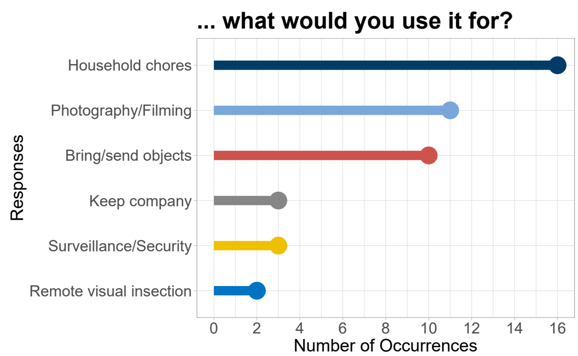

Fig. 6 Categorized responses to the question "If you had a personal autonomous drone, what would you use it for?" and their frequency. The most mentioned application is to help with household chores (i.e., cleaning, tidying, shopping, and taking care of animals).

Mode of Interaction

Participants were asked about their preferred modes of interaction with their personal drone (see Figure 7). The majority of participants mentioned using **vocal commands** or speaking to the drone naturally. Some participants also mentioned using an **interface screen** such as an app or computer, or incorporating **gestures** or body language along with vocal commands. Interestingly, a few participants mentioned the possibility of using a **brain-computer interface** as the ultimate mode of interaction. For example, one participant (P7) stated, "If there's anything better than voice, then I guess it's neural signals".

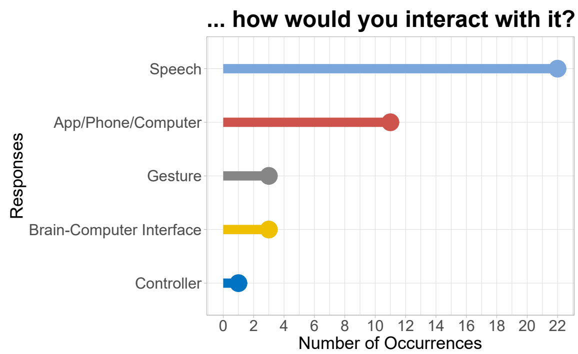

Fig. 7 Categorized responses to the question "How would you interact with it?" and their frequency. Most participants preferred speech interaction alone or in combination with other modes (i.e., non-verbal communication or screen interface).

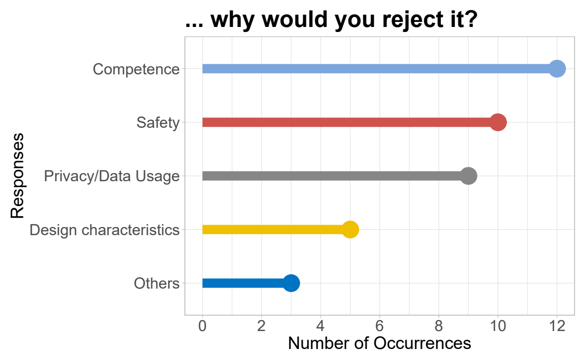

Fig. 8 Categorized responses to the question "Why would you reject the drone?" and their frequency. The inability to meet expectations in terms of performance was the first reason to reject the drone, followed by safety and privacy concerns.

Reasons for Drone's Rejection:*Performance, Safety, Privacy, and Design Concerns*

Participants cited several reasons why they would stop using their drone. The primary reason was the drone's **performance**, such as unresponsiveness, unreliability, and inability to avoid collisions (e.g., (P24) "If it does not do what I'm saying", (P36) "If I had to say commands like quite a few times. Or if it did the wrong thing.", (P18) "If it bumps too much into things"). Participants also expressed concern about the drone's **safety**, such as causing harm to people or damaging property. **Privacy and data usage** were also important factors for rejection, as some participants worried that their actions and conversations might be recorded and shared without their consent. Design characteristics, such as noise level and bulkiness, were also mentioned as potential reasons for rejection. Finally, some participants mentioned rejecting the drone for **other reasons**, such as difficulty in interacting with it, poor company updates, or having to pay a monthly fee to use it.

Social Acceptability

We asked participants how they would feel about using their drones around unfamiliar people. Some expressed concern about how others would perceive it, with one participant noting that it "**depends how socially acceptable it is**" (P38). Most participants said they would feel uncomfortable using their drones around strangers at this stage, but they believed this feeling would change as drones become more common. Others said they would not care either way. (P26) and (P18) said respectively they "**would not care**" if "I'm the only one" or "if they're annoyed".

When we asked participants how they would feel if someone else was using a drone near them, their responses fell into three categories: negative perception, neutral or positive, and context-dependent. **Negative perceptions** were mainly linked to potential annoyance, privacy, or safety concerns. **Positive perceptions** were related to adjectives like "interested," "curious," or "fascinated." Some participants expressed that their feeling would **depend** on how competent they think the drone is, how socially acceptable it becomes, and the purpose of the drone.

Preference for a Machine vs a Living Being

We inquired from the participants whether they would prefer a drone that displays social cues and emotions, making it more like a living being, or one that is purely machine-like. Surprisingly, responses were fairly evenly split. Participants who preferred a more social drone believed that it would result in better communication, personalization, and a more comfortable social presence, while also being less creepy. For instance, (P31) indicated that it "would make it easier to communicate with and talk to her." Meanwhile, (P7) "preferred something personalized like a personal butler," and (P35) said that "if you are interacting with an object, but the object does not learn how to interact with you, and it doesn't learn anything from you, it's very impersonal." For (P18), "it makes you feel like there's someone there, and that's nice," and (P36) indicated that they would prefer something closer to a living being "because I would see it more like a pet I think rather than like a weird thing watching me. Would be less creepy."

On the other hand, participants who were against a more social drone believed that it would be frightening, morally wrong, and potentially unnecessary. For example, (P12) said, "if there's a personality built into it would freak me out a little bit." According to (P21), "it would feel less morally wrong if it was more machine-like 'cause we do use them as slaves [...] We might as well not give ourselves the moral pain." (P30) mentioned that "it depends on what they want it to do. For example, I wouldn't like my coffee maker to be more human." (P35) added that "If it's for taking pictures, it's just a machine. If that's an object that I have to live with every day, so eventually I will develop some feelings towards the drone."

Public, Personal and Company Drones

In our exploration of a future in which drones are ubiquitous, we posited that companies and public services such as firefighters, police, and postal workers would utilize drones. We then asked participants whether they believed there should be differences between these drones and personal drones. Their answers fell into three categories: **aesthetic**, **regulatory**, and **functional** differences.

Participants expressed the expectation that such drones should be **clearly marked** to indicate the service or company to which they belong. One participant, (P4), suggested that "drones should have markings like they have on police cars and firefighter trucks" or "like people wear uniforms at work" (P21). Knowing the company or public service associated with the drone helps to "assess immediately what is the purpose of it" (P35). Additionally, some participants noted that it is particularly relevant for emergencies and public services as they may operate in areas where personal drones are not permitted, linking this to the second category of regulation.

Several participants recognized that public drones may have **more privileges** related to their role or the degree of emergency, but also emphasized the need to regulate these privileges to protect privacy. Some participants advocated for extending existing regulations to drones. For example, (P20) argued that "we have laws and regulations and human rights. [...] It should not be any different from what is supposed to be the actual practice of the police or the government". To support this, (P10) pointed out that "the police, unless they have a warrant, can't come into your house and things. You'd expect the same from the drone".

Finally, some participants expect public drones to have **specific design characteristics** that are tailored to their role and not available to personal drones. For instance, (P24) mentioned the speed limit of a police drone chasing someone, (P9) thought about their size "if it needs to take out the trash," and (P31) stated that "firefighting drones obviously have to have equipment and things that the personal drone doesn't need."

5 Discussion

In the following discussion section, we will analyze the findings of our proxemic experiment, which examined the influence of a drone's flying altitude and framing on participants' proxemic preferences. Our analysis will take into account the three proxemic functions (protective, communication, and arousal regulation) identified by Aiello [4], to provide a comprehensive interpretation of the results. Additionally, we will discuss the insights gathered from the semi-directed interview to further explore and clarify the quantitative measures, as well as to outline the current perception people have of the future of social drones and the use of Virtual Reality (VR) as an innovative approach for HDI proxemic studies.

5.1 Drones Above Us

In contrast to the behavior observed during Human-Human and Human-Robot interactions, our study found that participants walked closer to a drone as its height increased. We propose that this may be due to the proxemic protective function, which takes into account the participant's available space and perception of the drone's behavior. Unlike grounded robots and humans, drones occupy both physical and potential space differently, as they can move up and down and reach various locations. Given that we often see drones high above our heads, participants may anticipate a drone flying below eye-level (1 meter) or at eye-level (1.5 m) to take off and ascend.

Similar to how we do not expect a pedestrian walking forward to suddenly turn right, we do not expect a drone to abruptly land while carrying out a task. As a result, when the drone is high enough (above eye-level - 1.95 m), the space beneath it becomes partially available, and the maintained distance is reduced. Our findings suggest that stationary drones should fly above people instead of navigating around or beneath them in inhabited areas. However, it is essential to note that the experimental setting does not reflect the complexity of the real world, where people and drones may interact in various environments. Future research could investigate how environmental characteristics, such as space, bystanders, and obstacles, impact the transferability of our results to other settings. Additionally, while previous research has used the stop-distance procedure to examine the impact of drone height in front human-drone interactions, our study measured participants' paths when walking around a drone in a co-existing context. Therefore, our work provides a complementary contribution to the field by utilizing a different methodology and measuring proxemic preferences in a significantly different context. Measuring minimum distances best aligns with the core objectives of our study by providing a natural indicator of personal space boundaries. We nonetheless acknowledge that this metric does not capture all aspects of proxemic behavior comprehensively such as trajectory, speed dynamic, orientations. The exploration of novel proxemic measures that encompass a broader range of behaviors presents another intriguing avenue for future research.

5.2 Framing, a Double-Edge Sword

Despite providing participants with clear expectations and understanding about the drone prior to their first encounter, the social framing used in our study did not have the anticipated effect, as the social group maintained a greater distance from the drone compared to the technical group. We believe that the expectations induced by the social framing did not align with the reality of participants' experience with the specific drone used in the study. This potential mismatch may have resulted in the opposite effect of what we had predicted, and instead of promoting social comfort, the framing may have highlighted the lack of social features in the drone's design and interaction. This suggests that a mere description is insufficient to make a drone "social," but it can make this dimension more prominent.

However, beyond the interaction, our results indicate that some participants were prepared to engage with a social drone. Although they struggled to articulate their expectations, they clearly anticipated something distinct from a conventional AR Drone 2.0, implying that classic drones are not intended for social interactions. Other participants expressed disagreement with framing robots as social agents, preferring to regard them as tools. This disparity between the produced and individual frame may have resulted in greater physical distance, as previously observed by Banks et al. [12]. In contrast, the technical presentation was consistent with the drone's design and the overall experiment. Furthermore, some participants regarded the technical presentation as evoking a sense of safety rather than social interaction. Given that our participants came from scientific backgrounds, we believe that their pre-existing knowledge may have come into play. Not only were they more familiar with the terms used in the technical description, such as "deep reinforcement learning" and "neural network," but these words are also positively associated with advanced technology. As a result, the perceived threat level may have decreased or the drone's appeal may have increased, leading to a decrease in maintained distance. More broadly, as suggested by Entman [34], higher-level pre-existing frames, such as technology versus drone, can override or modify the produced frame, significantly influencing the outcomes.

While a technical framing served as an ideal contrast to the social one to verify whether we could artificially induce an increased sense of social connection through social framing, we may wonder what impact would a more "neutral" approach have had? Determining what truly constitutes a "neutral" framing is already debatable. The technical presentation was consistent with the drone's design and the overall experiment; hence one might argue it is already neutral. Another might say that a completely neutral approach would have been no framing at all, but then participants would be using their pre-existing frames of reference which is challenging to measure and control. Exploring the implications of different framing approaches, including potential neutral framing, could be an interesting avenue for future research.

5.3 Other Potential Factors: *Sound, Attention, Space and Drone's State*

The interviews conducted as part of the study revealed several additional factors that could influence participants' proxemic behaviors. Firstly, the noise generated by the drone was found to be a significant annoyance for participants, leading them to avoid it (arousal regulation function). Secondly, the task at hand seemed to divert participants' attention from the drone, potentially resulting in a reduced perceived threat and a lower maintained distance (protective function). Thirdly, some participants mentioned the size of the drone relative to the size of the room, suggesting that the size and context of the environment could be a factor affecting proxemic behaviors (related to available space and protective function). Finally, some participants reported increased trust over time as they became more certain that the drone would not move towards them, which suggests that a moving drone could induce different behaviors from participants as they continually update their predictions about the drone's movements (protective function).

5.4 The Future of Personal Drones

According to participants, in the future, people will naturally communicate with their drones to carry out various tasks both at home and outside. Personalized drones with advanced social features will coexist with more mechanical-looking ones. Private drones will differ in appearance to reflect their affiliation and function, while legal restrictions and capabilities will correspond to their purpose and allow them to operate in emergency situations. This vision aligns with the results of a previous study that explored social drones for the home environment from a user-centric perspective [49]. The feedback collected from participants in both studies was very similar regarding interaction preferences, applications, and the level of anthropomorphism desired in personal drones, indicating that people's projections for personal drones remain relatively stable over time. Furthermore, Herdel et al. [43] recently found that people have a more positive attitude towards drones' capabilities in severe contexts, which is consistent with the participants' feedback regarding the differences between public and personal drones. However, this exploration also highlights some challenges associated with the integration of drones into society, including high performance expectations, safety and privacy concerns, and complex design requirements.

5.5 Virtual Reality for HDI

The study used VR to examine how people behave when moving around a hovering drone. If the same experiment was conducted in the real world, safety measures would be necessary, which would impact the participants' perception of danger and their proxemic behavior. Instead, in the VR study, participants moved around freely in a one-to-one scale replica of the room. Some participants displayed risky behavior due to their curiosity, such as challenging the drone or trying to touch it. They even reported that they would be even more inquisitive if it were a real drone. VR allowed us to observe these types of behaviors that would be too dangerous to study in real-world experiments, but there are still questions about the ecological validity of VR.

While we limited our data collection to tracking the participants' positions over time using the VR headset, the expanding capabilities of VR technology present numerous avenues for exploring additional metrics. For example, the integration of eye-tracking technology in certain VR headsets offers the potential to quantitatively assess participants' focal points of attention during interactions with virtual elements, thereby enhancing our understanding of their cognitive responses and behaviors. Furthermore, other metrics pertinent to proxemics, such as participants' body orientations, movement trajectories, and speed, could be integrated into future studies using VR technology. We look forward to seeing how future research harnesses these opportunities to delve deeper into the realm of VR-based proxemic studies.

It should be noted that the results of proxemic studies in VR cannot be solely relied upon as an indicator of ecological validity. Various factors, including poor immersion but also personal comfort levels with drones, can influence the degree of close interaction. While participants in the study reported behaving naturally in the VR environment, the variability in their immersion levels highlights the subjectivity of this parameter. Researchers can only strive to enhance immersion, but cannot guarantee it. To improve ecological validity, one approach could be to determine a threshold level of immersion and then select participants accordingly. However, high immersion alone may not be enough if other variables impacting the investigated phenomenon are altered. For instance, in this study, some participants expressed that they would maintain a greater distance from the drone in the real world due to safety concerns, indicating that threat perception in VR can be distorted. Although a recent comparative study provides substantial evidence supporting the validity of our findings when compared to a real-world experimental setting, the authors of that study also propose that threat perception could be equally biased in both environments [17]. Therefore, we emphasize the importance of conducting additional research to explore how our findings might apply to real-world scenarios. However, despite these limitations, VR remains a valuable tool to investigate the potential impact of proxemic factors and can be used to generate hypotheses for real-world experiments.

6 Conclusion and Future Work

Our study examined the impact of flying height and framing on participants' proxemic preferences within a virtual environment. Our findings revealed that when participants were required to navigate around a stationary drone, they decreased their distance from the drone as its height increased. We attribute this behavior to the protective nature of proxemics and the available space. This observation has significant implications for the operation of drones in populated areas and suggests that they should fly at a safe height above people's heads.

We also found that there was no significant framing effect on proxemic preferences between the social and technical groups, despite a difference in the average minimum distance. However, our questionnaire results suggest that our framing successfully made the social dimension more prominent. The social group reported that the drone lacked social features, and their expectations did not align with a typical drone. We recommend further research to investigate the effect of social framing in association with socially-oriented features. Furthermore, researchers working in HDI should be mindful of how they introduce the drone to participants, as this could potentially bias the results.

Participants' expectations of future social drones were revealed through semi-directed interviews. They anticipate the use of personalized drones with advanced social features for various tasks both at home and outside, with different types of drones serving different purposes and being subject to legal restrictions. This aligns with previous studies and indicates stable projections for personal drones over time. However, the integration of drones into society presents challenges such as high performance expectations, safety and privacy concerns, and complex design requirements.

Finally, our study offers a proof of concept for using virtual reality in HDI research. The ability to manipulate the virtual environment can provide researchers with precise control over experimental variables, such as the drone's appearance and behavior, which can be challenging to control in the real world. Moreover, VR can provide a highly immersive experience that closely resembles real-world scenarios and can be adapted to fit a wide range of situations and populations.However, we caution that further research is needed to investigate how our findings might transfer to real world scenarios. Overall, our work contributes valuable insights into users' behavior around drones and demonstrates the potential of immersive VR in the HDI field.

7 Declarations

Funding and Competing interests. This work was supported by the UKRI Centre for Doctoral Training in Socially Intelligent Artificial Agents, Grant Number EP/S02266X/1. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical approval and Consent. This study adheres to the British Psychological Society ethical guidelines and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: [300210015]). Informed consent was obtained from all individual participants included in the study.The authors affirm that human participants provided informed consent for publication.

Data availability. The datasets generated during and/or analysed during the current study are publicly available on a dedicated GitHub repository (see [15]).

Appendix A Summary statistics

Table A1 Summary Statistics of the minimum distance grouped by Height and Framing. The mean varies between each condition of the two variables.

Height	Social	N	Mean(cm)	Sd(cm)
Above_Eyes	Social	23.00	99.10	49.00
Below_Eyes	Social	23.00	122.70	30.10
Eye_Level	Social	23.00	111.90	40.10
Above_Eyes	Technical	22.00	85.80	39.80
Below_Eyes	Technical	22.00	106.40	22.20
Eye_Level	Technical	22.00	97.70	26.30

Table A2 Summary Statistics of the minimum distance for each Framing condition. The average minimum distance is higher for the Social framing. Each participant provided three measurements, corresponding to the three height conditions, resulting in a total of 69 measurements for the Social framing and 66 measurements for the Technical framing.

Social	N	Mean(cm)	Sd(cm)
Social	69.00	111.30	41.00
Technical	66.00	96.60	31.10

Table A3 Summary Statistics of the minimum distance for each Height. The average minimum distance decreases as the Height increases.

Height	N	Mean(cm)	Sd(cm)
Above_Eyes	45.00	92.60	44.80
Below_Eyes	45.00	114.70	27.50
Eye_Level	45.00	105.00	34.40

Appendix B Cover Stories

B.1 Social framing - "Happy"

Let me introduce you to our Social Autonomous Drone, which makes SAD for an acronym, hence we name him Happy! Happy is a social robot which means its purpose is to interact with people to collaborate or assist them in their daily life or for more specific tasks (i.e., assist firefighters to reach tricky spots, personal flying assistant, help rescue teams to locate injured people, guide joggers during their runs or provide a comforting presence for elder people). But as a guide dog was once a clumsy puppy, Happy is not ready for the field yet and has a lot to learn. In this experiment I will observe Happy while you perform a task in the environment. As a dog knows "sit", "come", and "Fetch!", Happy is able to understand "Happy, look for my keys", and "Happy, Land".

A bit of context.

Basically, imagine you are at home, and you ask Happy to look for your keys, so it requires him to fly in a stationary position (meaning he does not move from its location). At the same time, you want to do something in the room which requires you to cross the room (i.e., reach the button at the other end of the room to switch the light on). You will have to move within the place while Happy is busy flying, looking for your keys. It is this kind of situation we want to replicate here.

Before the detailed protocol is explained, could you please answer the short questionnaire that you will discover by clicking on next? Keep in mind that there is no wrong answer, only your opinion matters.

B.2 Technical framing

The AR 2.0 ® drone is a quadrotor unmanned aerial vehicle (UAV). Taking advantage of its onboard camera and rounded propeller guards, it can be used for indoor or outdoor leisure flying and aerial shots. Initially remotely controlled using a smartphone or a tablet, we have developed a machine learning based flying system, which basically learns through practice how to fly around people within inhabited environments. The drone's behavioural system is built using a deep reinforcement learning approach. It combines the use of an artificial neural network and reinforcement learning. Based on a set of conditions, the optimal action of the drone is approximated and associated with a computed expected reward. In this experiment I will observe the drone while you perform a task in the environment. Currently, the AR 2.0 is able to understand "Drone, look for my keys", and "Drone, land".

A bit of context.

Basically, imagine you are at home, and you ask the drone to look for your keys, so it requires it to fly in a stationary position (meaning it does not move from its location). At the same time, you want to do something in the room which requires you to cross the room (i.e., reach the button at the other end of the room to switch the light on). You will have to move within the place while the drone is flying and performing a task. It is this kind of situation we want to replicate here.

Before the detailed protocol is explained, could you please answer the short questionnaire that you will discover by clicking on next? Keep in mind that there is no wrong answer, only your opinion matters.

Appendix C Description of drones

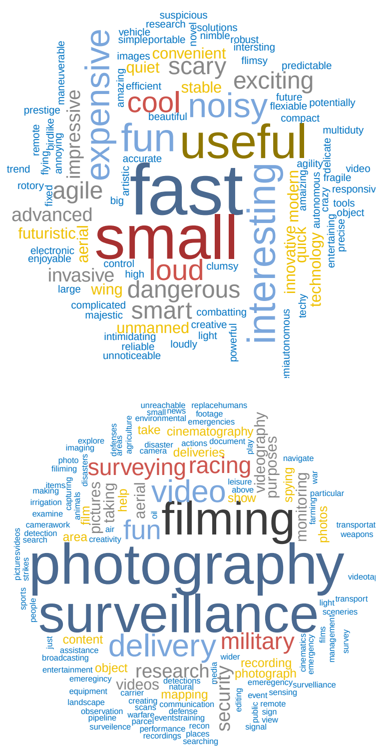

Fig. C1 Word Cloud of the adjectives used to describe drones (top) and applications people were aware of (down). The size indicates the term's frequency (e.g., f("fast")=14, f("useful")=9, f("noisy")=6)). Seventy-two persons answered the demographic questionnaire providing the data for these charts. From these individuals, 45 then participated to the user study.

Appendix D Participant protocol

The only difference between the technical and social protocol is that in one case we refer to the drone as "The drone" and in the other case as "Happy".

D.1 Protocol - Social

You understand that both you and Happy will have to achieve something in parallel. So first, to initiate Happy's task, you will ask him to search for your keys by saying "Happy, look for my keys". You will then perform your own task and once it's done, you will end Happy's task by saying "Happy, land". Now, what about your task? You may have noticed that papers of colour are located on the walls and on the table next to your initial position. When Happy will take off (after your vocal command), a sequence of colours will appear on the paper located on the table behind you. Your task is to reach and touch the papers of colour in the same order as the sequence. So, if you read "1. Red, 2. Purple, 3. Black", you will have to reach the red paper first, then the purple and finally the black one. It is important that you respect the colours and the order. Once you did it, you can go back to your initial position. And as your task is over, you can ask Happy to land by saying "Happy, Land". You will repeat this procedure three times. Meaning that once your assistant has landed, you will ask again "Happy, look for my keys", a new sequence of colours will appear, and you know what to do next. While you move in the room just let Happy focus on its task while you focus on yours.

D.2 Protocol shematic - Social

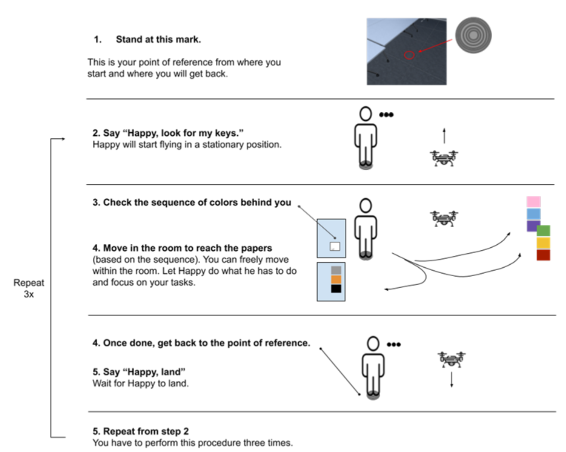

Fig. D2 Participant protocol shematic for the social cover story.

Appendix E Interview Guide Sheet

Fig. E3 Interview Guide Sheet: As the interview was conducted in a semi-directed format, it's important to note that not all the questions listed in this guide sheet were necessarily asked during the interview. Follow-up questions, which might not be included here, were posed as the conversation naturally evolved. Additionally, the phrasing of questions may have varied, and there was no strict adherence to a chronological order in presenting them.

Cultural Background

…
So, I see you grew up in [INSERT WORLD REGION]. Do you think your perception of the drone and the way you interacted with it may have been shaped or at least influenced by your culture?

Drone perception

If you remember the Pre-study Questionnaire, there was a question where you had to select some adjectives to describe the drones you had encountered before… I see that you used: [INSERT ADJECTIVES]. Why did these adjectives come to your mind when thinking about drones?
…
Would you change these adjectives based on the interaction you just performed?
…
What is your opinion about [“Happy”/The AR 2.0]?
…
What do you think of its appearance (size, form, color)/ the way it flies / the sound it makes?
…
If you could change something about these different aspects, what would it be? … Why?
…
Do you think that if we presented you the drone in a more [social/technical] way, it would have changed your perception and the way you interacted with it? --- *Then give the other presentation and ask again.*

Drone uses

When presenting the drone, we evoked some uses but nothing very clear.

Personal Drone
If you had a personal autonomous drone, how would you use it? What tasks would you want it to perform?
…
So more an [inside/outside] drone?
…
How do you picture yourself interacting with it? … Would you speak to him, touch it, gesture, control it remotely? …
…
What could make you reject it?
…
Would you prefer a tool of something closer to a living being?
…
How would you feel about using it next to people that you don’t know?
…
How would you feel if someone that you don't know is using their drone next to you?
Public Drone
…
Now if we think of a drone that could be used by public organizations rather than individuals, for instance firefighters, delivery companies, etc., how should they be used in your opinion?
…
What would be your main concerns knowing there are public drones flying around? How would you feel about it?
…
Do you think the design of public and private drones should be different?

Physical perception

Now let’s focus on your experience during the experiment.
…
Where was your attention focused during the different steps of the experiment?
…
How did you feel when approaching the drone?
…
In your opinion, what were the main elements of the environment that made you behave the way you did? On the contrary, what was unimportant?

Virtual reality

I see you are [not/well/very well] familiar with Virtual reality. The use of this tool for research is one of our main research axes, so your feedback is precious.
…
How would you describe the virtual environment you were immersed in?
…
To which extent did you believe the drone was real? Did you think the drone could touch you?
…
Compared to a real-world environment, what do you think was missing to make it more compelling?
…
Do you think you would have behaved the same way in a real-world experiment with a real drone? Why?

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