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Co-existing With a Drone: Using Virtual Reality to Investigate the Effect of the Drone's Height and Cover Story on Proxemic Behaviours

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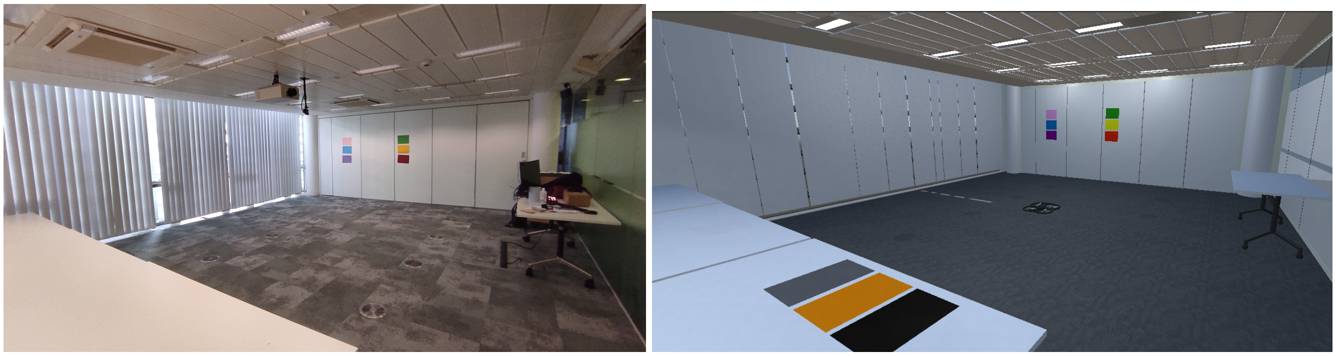

Figure 1: The experimental room (left) next to its virtual replica (right) in Unity 3D. Participants' paths were recorded in the simulation (see Figure 2), allowing the accurate assessment of proxemic preferences around the drone, in a safe and realistic environment.

ABSTRACT

While a growing body of literature has begun to examine proxemics in light of human–robot interactions, it is unclear how insights gained from human–human or human–robot interaction (HRI) apply during human–drone interactions (HDI). Understanding why and how people locate themselves around drones is thus critical to ensure drones are socially acceptable. In this paper, we present a proxemic user study (N=45) in virtual reality focusing on 1) the impact of the drone's height and 2) the type of cover story used to introduce the drone (framing) on participants' proxemic preferences. We found that the flying height has a statistically significant effect on the preferred interpersonal distance, whereas no evidence was found related to how the drone was framed. While results also highlight the value of using Virtual Reality for HDI experiments, further research must be carried out to investigate how these findings translate from the virtual to the real world.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Human computer interaction (HCI)**.

KEYWORDS

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

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1 INTRODUCTION

As drones become easier to use, as well as cheaper and safer, the number of practitioners continues to increase (+8.5% recreational registration to the Federal Aviation Administration (FAA) between 2019 and 2020).[3] Some of the commercial applications already in use include in construction [5, 51], policing [28], fire fighting [7, 44], delivery [32], and more. It thus does not seem far fetched to predict that for many people, it might soon seem normal to interact with drones on a daily basis. Since autonomous entities will evolve in social and inhabited environments, it is critical to investigate their relationship with users and bystanders. In their analysis of the literature around social drones, Baytas et al. define social drones as autonomous drones operating in inhabited environments (e.g., home, cities) [13]. They have identified six drone design concerns and six human-centered concerns. One of these concerns relates to proxemics. Indeed, when deployed in social spheres, drones must navigate in a socially acceptable and human-friendly way. It is

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therefore critical to understand why and how people locate themselves around drones. Unlike humans or ground/non-aerial robots, drones can fly, and most casual encounters with drones will happen as they fly. In addition, the frame through which people perceive drones is critical for their integration to society (see subsection 2.3).

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. We found that the flying height significantly impacts people's preferred interpersonal distances. 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. This work contributes to the HDI field by providing new insights into 1) users' behaviors around drones when co-existing in the same space, and 2) how this behavior is impacted by the drone's height and its framing. The results should help designers prepare and adapt the drone's navigation path in social and inhabited environments. It might also inform companies, public services, etc., how to present their drones to foster a positive user perception when deployed in public spaces. Moreover, this attempt to use an immersive virtual environment for an HDI experiment may pave the way to a series of new experiments promoting mundane realism, control, safety, freedom, and ecological validity.

2 RELATED WORK

2.1 Proxemics

2.1.1 *Proxemic functions: Communication, protection, arousal regulation.*

As pointed out by Aiello in his review of the research in human spatial behavior [4], many theoretical frameworks for proxemics exist. From these models, Aiello identified three main reasons why people maintain a certain distance between themselves and another agent: **(1)** to avoid excessive arousal stimulation and stressors induced by others' proximity (arousal regulation function) [59]; **(2)** to retain some behavioral freedom to react to potential threats (protective function) [18, 24]; and/or **(3)** to communicate the type of relationship/level of intimacy between the interactants (communicative function). As robots are not necessarily perceived as social entities by the users, the communication function seems limited in explaining proxemic behaviors around robots. This is especially the case with drones as they do not generally show anthropomorphic features. Hence, as suggested by Leichtmann in his meta-analysis of proxemics in human–robot interaction [49], we will return to these three functions to frame the interpretations of the results.

2.1.2 *Human-Drone Proxemics.*

So far, researchers have explored how drones should approach people [42, 66], the distance at which people feel comfortable around drones, what factors impact this distance [25, 26, 36, 52, 67], to which extent it differs from ground robots [2] and interaction methods that rely on close proximity [1, 8, 17, 53]. More specifically, investigating the effect of a drone's height on comfortable distance, Duncan and colleagues and Han and colleagues did not report any effect of the flying height comparing high (2.13m) with low (1.52m) hovering heights [25] and a drone overhead (2.6m) with eye level (1.7m) [36] respectively. Yet, the techniques they used to ensure participants' safety made these results questionable by impacting the ecological validity of the experiment. Indeed, the constraints of reality and the risks associated with drones flying in close proximity to people have hindered the research within this field. Associated safety measures critically challenge researchers' ability to perform real-world experiments, thus compromising the ecological validity of research in this domain. Researchers have used a transparent safety wall [36], fixed the drone's position [25, 67], used a fake drone [19], or limited the minimum distance between a drone and a human [2, 25, 36] to investigate proxemic preferences. All of these choices have the potential to significantly impact the results. To tackle these issues, we chose to investigate the use of VR as a testbed for HDI proxemic studies.

2.2 VR as a methodological tool

The distance people maintain between themselves and others relies on the perception and interpretation of sensory inputs. Consequently, VR can impact known proxemic factors such as the perception of distances [41, 46, 57], motor abilities [6, 30], or threat perception [22, 34, 54]. However, the ecological validity of Immersive virtual environments (IVEs) has been verified in certain contexts.[23, 30, 58] Not only would it counter the real-world issues mentioned in Section 2.1.2, but VR also has the potential to "eliminate the trade-off between mundane realism and experimental control, [. . .] target population more representatively and reduce the difficulty of replication" [14]. IVEs have already been used successfully for human–human [14, 40, 48, 61] and human–robot proxemic studies [62], and more recently to test innovative drones' appearance [16, 43]. It is safe and reproducible and Wojciechowska et al. have classified VR as the second-best method in terms of realism behind the collocated flight [66]. Several recent works have further highlighted the significant potential of remote VR experiments [55, 56], and VR headsets' increasing popularity and cost/performance ratio foresee a radiant future.

2.3 Framing

2.3.1 *Theoretical background.*

In addition to the drone's flying height, we also explored the extent to which framing can impact participants' proxemic behavior around a drone. Frames are "discursive structures that make dimensions of a situation more or less salient" [12]. Framing (the process of creating a frame) consists of *selection* and *salience.* [29] When communicating (i.e., speech, text, video) about an item of interest (i.e., situation, object, person), selecting or omitting a specific bit of information makes certain aspects of this item more or less meaningful or noticeable. Yet existing individual frames [63] can shape the results of the framing. For instance, hidden information might be brought back, highlighted elements minimized, and a mismatch between the individual and produced frames can induce a resistance of the framing [29]. It can end up with no or opposite effect [12]. Moreover, produced frames will be more resilient when they appear at a medium-level knowledge of the receiver. [47]

2.3.2 *Framing for HDI.*

Consequently, understanding how framing impacts the relationship between people and drones is critical for their integration into society, especially at the early stage of HDI. Indeed, currently, just a few people can boast about having a great experience with drones. In fact, the produced frame which the majority of people have related to drones is characterized by its precariousness (it rests on few elements), relative instability (can be easily changed as a new element appears), and randomness (hard to predict the sources of influence and resulting frame). And people with moderate knowledge are more persistently impacted by new inputs (new frames) [47]. Hence, at the first encounter, a participant who has heard of drones only through accidents shared in the news will likely be concerned about their potential danger. It has also been shown repeatedly that it is possible to use framing effects to impact people's immediate reactions to a robot, such as making them perceive the robot as more (or less) social or friendly or human-like [20, 21, 39, 45]. We could then make certain dimensions of the drone more salient to serve our objectives (e.g, reassure a injured person during a rescue mission). Hence, if not carefully considered, it can also unintentionally bias the results of an experiment. For instance, Chang et al. framed drones as a threat to privacy before assessing participants' concerns about them. Not surprisingly, the experimenters reported "more in-depth negative aspects of drones than positives, which stands in contrast to findings in prior works" [19]. The framing effect has already been explored in some human-robot interactions works [10–12, 21, 27, 31, 60], but it is less explored in HDI [37, 38]. In practice, our work could inform companies, public services, etc., how to present their drones to foster a positive user perception when deployed in public spaces.

3 METHOD

This experiment investigates the effect of an 1) induced framing and 2) the drone's flying height on 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 [35]. Consequently, we believe that measuring proxemic preferences using the stop-distance procedure (see [25, 50]) is not ideal in terms of ecological validity as the core process of distancing is brought to the consciousness and necessarily altered. On contrast, we observed proxemic behaviors while the participant performed a task that indirectly requires passing by a flying drone (see Figure 2). We use the VR headset's position in the IVE to record participants' movements and precisely assess interpersonal distances between each participant and the drone. This approach was successfully used in previous proxemic experiments [9]. Prior to data collection, all manipulations, measures, sample size justification and main hypotheses were pre-registered on the Open Science Framework (OSF): https://osf.io/7a4xu. Consistent with recent proposals [33], we report all manipulations and all measures in the study.

3.1 Experimental Design

The experiment follows a 2 x 3 mixed split-plot design. The between-participants factor of 'Framing' (independent variable) has two levels: social and technical. Participants are divided into two groups that read different presentations about the drone before the task. The social-oriented framing text assigns a name to the drone, describes social applications, and uses a pet metaphor to induce a social framing of the drone. Conversely, the technical-oriented presentation is very descriptive and only contains technical terms (see Appendix B), while matching the social framing text in other surface features of the text. The participant's perception of the drone before their first encounter was assessed during post-experiment interviews. The within-participants factor of flying height (independent variable) has three levels: above the eyes (1.95m), eye-level (1.5m), and below the eyes (1m). Different categorical levels (i.e., tall, short, overhead, eye level) associated to fixed drone's heights have been explored in previous experiments[25, 25, 36, 67]. In this experiment, we consider the drone at eye_level when bewteen +/-15cm relative to the participant's eyes height. The maximum drone's height (1.95m) was limited by the room dimensions. The system samples participant-drone distance at a fixed frequency (5 Hz). It allows us to draw the participants' paths to complete the tasks as seen on Figure 2. We consider personal space as the minimum distance between the participant and the drone for each condition set (dependent variable). This distance was measured using position of the user's head (VR headset) relative to the drone in the virtual environment. Baileson et al. used this measure for a similar procedure [9]. As the time to complete the tasks and the characteristics of participants' movement differ (speed, amplitude), the average distance is irrelevant. The height conditions' order has been randomized using a Latin square.

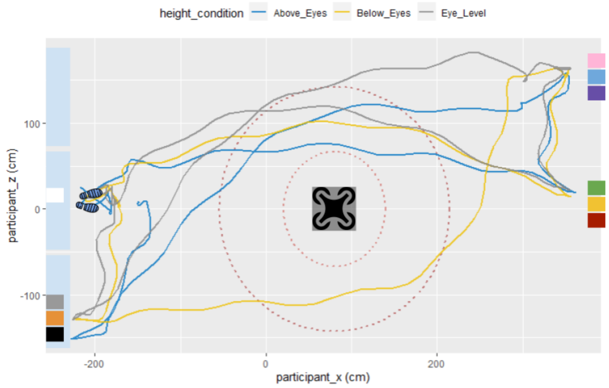

Figure 2: Top view of a participant's path as they walk from the starting point (footprints) around the virtual drone to reach the colored papers (colored squares) in the room. The sequence to follow appears on the paper (white square) located on the table (blue rectangle) next to the initial position.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

3.2 Setup and apparatus

We have developed the virtual environment in Unity 3D. It consists of a replica of a real-world room in our department where the experiment is conducted. For the participant's task, colored papers were put on walls and the table next to the initial position in the virtual and real-world (see Figure 2). We have intentionally created similar environments to increase the presence [65]. As the dimensions are the same and participants wear a mobile VR headset

(Oculus Quest 2), they could move within the entire room without dealing with cables, virtual walls, or unexpected obstacles. The virtual participant's position is calibrated with the real one, meaning that when they touch the virtual wall or table, they feel the real one simultaneously. They have their hands free and can see them in the simulation (they do not use controllers). The virtual drone (Parrot AR 2.0) is controlled via a C# script with predefined realistic animations to ensure high replicability. In a Wizard of Oz approach, the participant pronounced voice commands and then the experimenter used the VR controller to run the animations. The virtual drone's behavior is intended to replicate the real drone's behavior. Previous works have reported the sound of the drone is a critical component of the user experience. Hence, we added spatial drone audio when it flies and lands in VR.

3.3 Participants

Before coming to the lab, participants answered a questionnaire to collect their demographics, prior experience with drones or virtual reality, adjectives they would use to describe drones, and the applications they are aware of. We recruited 45 participants (27 male, 17 female, one non-binary), mainly students from scientific backgrounds (computing science, psychology, veterinary), between 17 to 38 years old (M=25.25, SD=5.37) and with various experience with drones and VR and from multiple origins. We measured the participants' eyes height using the average headset height during the simulation (min=136.4cm, max=174.5cm, M=155cm, SD=9.5cm). We randomly assigned each participant to one of the two groups (social/technical), trying to maximize the gender parity and reach a similar size.

3.4 Protocol

After we welcomed them to the experimental room, they filled in the consent form, and we explained that we have replicated the room in VR. Then, participants read a short cover story (see Appendix B) about the drone they will interact with. Following the presentation, they filled in the RoSAS [15] to assess their initial perception of the drone. Participants then read the protocol (see Appendix C) and put on the Oculus Quest 2. They were directly immersed in the virtual room. At that point, they could ask the drone to search for their keys by saying, "Drone/Happy, look for my keys". The choice of “Drone” or “Happy” depended on the framing. Afterwards, the drone takes off, and a sequence of three words referring to colors appears on the table next to the participant (see Figure 2). Their task was to memorize it, to reach and then touch the colored papers in the same order. Once they touched all the papers, they went back to the initial position. As their task was over, they could ask the drone to land, saying, “Happy/Drone, land”. Participants repeated this procedure three times (for the three height conditions). Each time a different sequence of colors appeared. The initial position, papers' location, and arrangements forced the participants to pass by the drone from the front and then diagonally for each height condition. After the experiment, they answered the IPQ [64] to assess their perceived sense of presence. We concluded with a semi-directed interview (30-45 minutes). It helped us better understand the results (existing/new frame, VR experience, identification of proxemic factors) and explore different ideas (future of drones, social drones, open discussions).

4 RESULTS

In addition to developing VR as a methodological tool for HDI studies, this experiment investigates the effects of the flying height and framing on participants' proxemic preferences. We performed a mixed ANOVA with one between-participants factor (Framing) of two levels, and one within-participant factor (Height) of three levels (2b*3w). The dependent variable is the absolute minimum participant-drone distance for each set of conditions. We verified the normality assumption (Shapiro-Wilk test, $p > 0.05$) and the homogeneity of variances (Levene's test, $p > 0.05$) and covariances (Box's test of equality of covariance matrices, $p > 0.001$). Our test internally assesses the sphericity assumption (Mauchly's test). It automatically applies the Greenhouse-Geisser sphericity correction to factors violating the assumption. The test revealed a significant main effect of the Height ($F(2,86) = 14.948$, $p = 2.68e-06 < 0.0001$, ges=0.062), but we found no significant effect of the Framing and no interaction between the two variables.

Height. Bonferroni-corrected multiple pairwise paired t-tests revealed a significant difference between each *Height* condition (see Table 1 and Figure 3). There is a significant difference between *Above_eyes* (M=92.6cm, SD=44.8cm) and *Below_eyes* (M=114.7cm, SD=27.5cm) ($p<0.0001$), *Above_eyes* and *Eye_level* (M=105cm, SD =34.4cm) ($p<0.05$), and *Below_eyes* and *Eye_level* ($p<0.05$). Participants get significantly closer to the drone when it is above their eyes and maintain a significantly greater distance when it is below the eyes compared to the other two conditions.

Framing. To assess the effect of *Framing* on participants' perception of the drone before their first encounter, we used the RoSAS [15]. It consists of 18 items, divided into three factors: warmth, competence, and discomfort. The computed score of each factor corresponds to the mean of their associated items' score. We performed a Welch two-sample t-test for each of these constructs. It showed a statistically significant difference for the Warmth ($t(41.14) = 3.4938$, $p < 0.005$, $d = 1.030259$) rating. Participants' feedback supported this result during the post-experiment interview. This shows that we successfully made the social dimension of the drone more salient. However, while we expected participants to maintain a lower distance with “Happy”, in line with these participants being more comfortable with the socially-framed drone, in fact, we found that the opposite happened. On average, the social group maintained a greater distance (M=111.3 cm, SD=41 cm) than the technical one (M=96.6 cm, SD=31.1 cm). This difference is not statistically significant hence we cannot generalize this result. This finding remains curious and will require further follow up.

5 DISCUSSION

This proxemic experiment aimed to investigate the impact of a drone's flying height and its contextual framing on participants' proxemic preferences. We consider the three proxemic functions (protective, communication, arousal regulation) identified by Aiello [4] in our interpretion of the results.

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

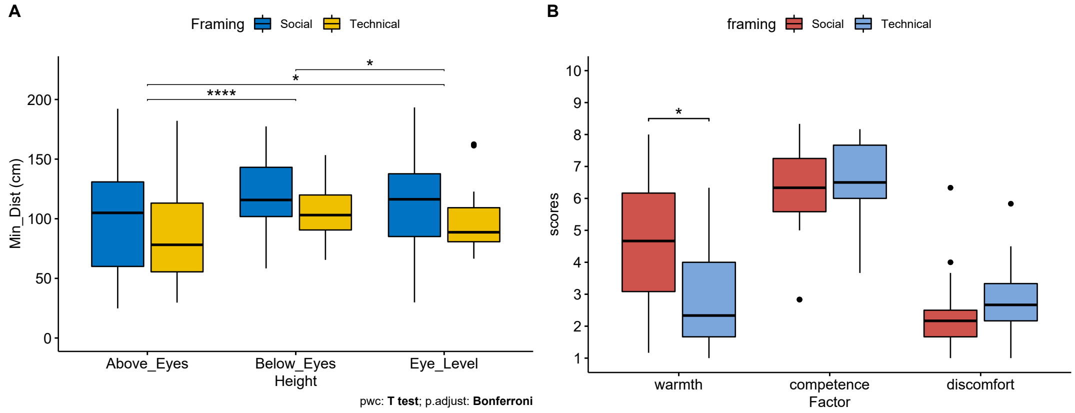

Figure 3: A. Effect of the *Height* on the distance for each *Framing* condition (** p<0.0001, * p<0.05). The boxplot indicates a significant decrease in the minimum maintained distance when comparing Above_eyes with Eye_level and Below_eye, and Eye_level with Below_eyes. B. Effect of the *Framing* on 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.**

5.1 Drones above us

Contrary to what we could observe during Human–Human and Human–Robot proxemic behaviors, the higher the drone was positioned, the closer participants were happy to position themselves to it. We believe this can be explained through the proxemic protective function, considering the participant's available space and projection of the drone behavior. The taller grounded robots and humans are, the more they occupy actual (physical) and potential (reachable distance) space and reduce others' available space. But the relation between the drone's height and its actual/potential occupied space is different. Now, as we see drones far above our heads most of the time, participants might expect a drone flying below the eyes (1 meter) or at eye-level (1.5 m) to take off and go up. And the same way we do not expect a passer-by walking forward to turn right suddenly, we do not expect a drone to suddenly land when performing a task. Consequently, when the drone is sufficiently high (above the eyes - 1.95 m), the space below it becomes partially available, and the maintained distance is reduced. These results suggest that stationary drones should fly above people rather than navigate around them or below them when operating in inhabited areas. Yet the simplicity of the experimental room does not reflect the complexity of the real world where drones and people might collectively evolve. Further research could investigate the impact of the environment's characteristics (space, bystanders, obstacles) to better understand the degree to which the present results can be transferred to other settings. While previous works investigated the drones' height impact using the stop-distance procedure in the context of front human-drone interaction, we measured participants' paths when walking around a drone in a co-existing context. Hence this work provides a complementary contribution to the field by using a different methodology and measuring proxemic preferences in a significantly different context.

5.2 Framing, a double-edge sword

Despite giving participants a clearer understanding and expectations about the drone before the first encounter, the frames we used in the present study did not have the expected effect. We think that the expectations induced by the social framing did not match the reality of people's experience with the particular drone they encountered in the study, potentially leading to the opposite effect to what we predicted. Rather than creating a social comfort (as suggested by the RoSAS scores), the frame pointed out the lack of social features in the drone design and the interaction. Hence a description per se is not enough to make a drone "social", but it made this dimension more salient. However, beyond the interaction, it shows that some participants were ready to interact with a social drone. They struggled to describe what they expected, but clearly expected something different from a "classic" AR Drone 2.0 (suggesting that classic drones are not designed for social interactions). Other participants mentioned their disagreement with framing robots as social agents rather than tools. This mismatch between the produced and individual frame may have resulted in greater physical distance, as previously found by Banks et al. [12]. On the other hand, the technical presentation was consistent with the drone design and the overall experiment. Moreover, some participants even found the technical presentation to evoke a safer rather than the social drone. As we had participants from scientific backgrounds, we believe their preexisting knowledge came into play. Not only were they more familiar with some terms used in the technical description ("deep reinforcement learning", "neural network"), but these words are also positively associated with high-level technology. The perceived threat level might have been consequently reduced, resulting in a decreased maintained distance (protective function). More generally, as suggested by Entman [29], pre-existing frames of higher level (technology>drone) can override or impact the produced frame, significantly impacting the results.

5.3 Other potential factors: *sound, attention, space and drone's state*

Through the interviews, we also identified other potential factors influencing proxemic behaviours. **1)** The annoyance generated by the drone's noise seems to be a considerable reason why participants wished to avoid it (arousal regulation function). **2)** The task to perform diverted the attention from the drone, potentially resulting in a decreased perceived threat and lower maintained distance (protective function). **3)** Participants commented on the drone's size relatively to the size of the room. Hence the size and context (i.e., indoors vs. outdoors) of the surrounding environment might be a factor (related to the available space and protective function). **4)** Some participants reported increased trust over time as they became sure that the drone would not move toward them. It seems reasonable to expect that a moving drone would induce different behaviors from the participant, likely due to participants continually having to update their predictions about where the drone is currently, and where it is likely to go next (protective function).

6 CONCLUSION AND FUTURE WORK

We investigated the effects of flying height and framing on participants' proxemic preferences in a virtual environment. We found that, when performing a task that requires passing by a drone flying in a stationary position, participants decreased the distance they maintained with the drone when it hovered higher. This observation has been attributed to the proxemic protective function and participant's available space. It suggests that drones should operate (well) above people's heads in inhabited areas. Further, we found that despite a different average minimum distance between the social and technical groups, no significant framing effect on participants' proxemic preferences emerged.

Through the interviews, we also identified other potential factors influencing proxemic behaviours, including the sound (linked to the arousal regulation function), the amount of attention attributed to the drone, the size of the room, and the drone's state (related to the protective role). Many papers report the sound of the drone as a critical characteristic, but none focus on its impact on proxemic behaviors. Further research could explore the impact of these potential factors on proxemic preferences. Finally, our results provide a proof of concept and also raise issues for consideration for researchers wishing to use VR for HDI proxemic experiments. With that being said, we nonetheless urge follow-up research to investigate how these findings might transfer to the real world. In particular, it will be important to determine just how much VR alters physical threat perception [34, 54]. This work contributes to the HDI field and provides precious insights into users' behavior around drones. We used a promising novel approach in HDI, and despite its limitations, immersive VR remains a good alternative to constrained real-world HDI experiments.

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A SUMMARY STATISTICS

Table 2: 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 3: Summary Statistics of the minimum distance for each Framing condition. The average minimum distance is higher for the Social framing.

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

Table 4: 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

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.

C 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".

C.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.

C.2 Protocol shematic - Social

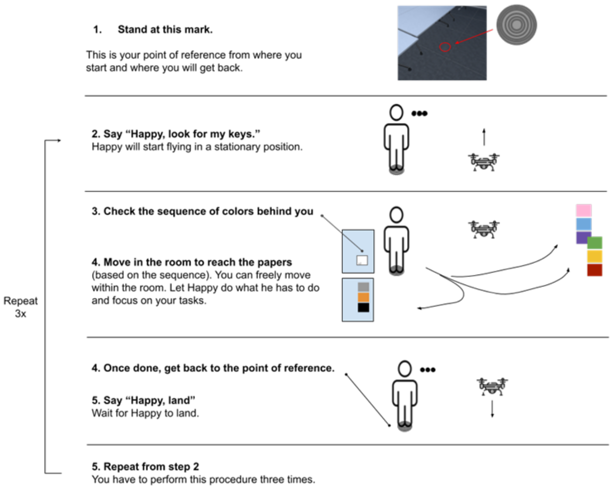

Figure 4: Participant protocol shematic for the social cover story.