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Exploring Intended Functions of Indoor Flying Robots Interacting With Humans in Proximity

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Figure 1: Overview of the interaction involving a flying drone (positioned in the upper middle of the photo), a participant wearing protective goggles (on the left, played by a researcher), and the experimenter acting as a host (on the right) during the briefing phase. On the screen, icons representing the intended functions - *camera*, *education*, *pet* - are demonstrated. Each icon will be displayed individually based on the respective scenario, while the screen will remain blank for the *unknown* function. Two marks on the long table indicate two distances, *near* and *far*, from where the drone will take off correspondingly.

ABSTRACT

What will people experience when drones become common in home environments? How will their functions and distances impact human experiences? To explore the potential usage of indoor drones, we conducted a mixed-methods study (N=60) on the reported perceptions of a small flying robot. We employed a factorial experimental design, involving four intended drone functions (*camera*, *education*, *pet*, *unknown*) at two distances (*near*, *far*). Our findings suggest that intended functions significantly influence participants' perceptions. Among the functions examined, participants found the *camera* useful but annoying, and the *pet* useless but pleasant. The *education* emerged as the most favored function, while the *unknown* function was the least preferred one. Based on these findings, we discuss implications for designing positive interactions between humans and indoor drones, considering aspects such as context, transparency, privacy, technical factors, and personalization.

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CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Scenario-based design**; • **Hardware** → *Emerging interfaces*; • **Computer systems organization** → *Robotics*.

KEYWORDS

Indoor drone, drone function, proxemics, human-drone interaction (HDI), user experience (UX), artificial intelligence (AI).

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1 INTRODUCTION

The vision of ubiquitous flying robots, or autonomous drones, is becoming increasingly popular. Therefore, it is important to develop a more profound understanding of how our interactions with this emerging technology will evolve. On the one hand, predominant drone applications have mainly revolved around activities such as aerial photography, express delivery, and various other functions [25, 29], primarily carried out outdoors. On the other hand, the notion of indoor drones remains relatively unfamiliar to the general public. What kind of experiences can people expect once drones become a prevalent presence within household environments?

While there has been significant research on how people interact with flying robots, also called human-drone interaction (HDI), these works (e.g., [5, 27, 43]) often overlook the differentiation between indoor and outdoor drone usage contexts. Yet, indoor and outdoor drones differ markedly in terms of design factors [25] including size, capability, cost, and other attributes, thereby giving rise to different levels of noise, diverse functional requirements, and distinct applicable scenarios. This naturally leads to a variety of interaction possibilities and challenges involving both users and bystanders. In spite of these challenges, application scenarios of indoor drones within human-inhabited environments have received limited research attention. Specifically, there is a notable lack of basic comprehension regarding how intended functions or potential use cases might influence individuals' perceptions of indoor drones. As we see it, further exploration is needed to systematically approach the design of functions of indoor flying robots operating in close proximity to humans.

The word "function" means "the purpose or intended role of a thing" [44]. In this paper, the term "intended functions" refers specifically to the functions we communicated to participants that we intended to incorporate into the drone, given that the flying robot we employed was a prototype rather than a fully developed product. Following a Research through Design (RtD) approach [73], we opted to explore four distinct intended functions. Specifically, participants were apprised that the indoor drone was utilized either as an indoor aerial camera, an educational tool, a robotic pet, or an undisclosed function. We abbreviated these functions as: *camera*, *education*, *pet*, and *unknown.* We conjecture that the intended function will have an impact on people's perceptions of indoor drones and that user-drone proximity may also affect this perception. We designed a mixed-methods empirical study to examine our hypothesis.

The contributions of this paper are: (i) Presenting an empirical study that investigates the correlation between intended functions and proxemics of indoor flying robots and their impact on human perceptions, addressing research gaps. (ii) Providing both quantitative evidence and qualitative insights, revealing that the intended functions of indoor drones may be a pivotal factor in impacting human perceptions and overall user experience. (iii) Exploring and evaluating potential use scenarios of indoor drones, leading to reflections and recommendations for designing interactive flying robots and guiding future research. The originality of this study lies in its systematic exploration of the effects of functions and proxemics on users' experience with indoor drones through a controlled factorial experiment, along with the empirical validation of both previous concepts and novel prototypes.

2 BACKGROUND AND RELATED WORK

In this section, we provide a basis for our study by addressing gaps in the current literature.

2.1 Indoor Human-Drone Interaction (HDI): Underexplored, Differing from Outdoor Contexts

Drones have gained immense popularity as versatile tools across various applications. Extensive reviews [5, 27, 43] shed light on the multifaceted utility of drones, which encompassed diverse domains, ranging from emergency response, entertainment, and communication to sports, assistance, security, companionship, law enforcement, navigation, and more. Their findings collectively underscore the widespread interest and diverse applications of drone technology. However, it is worth noting that these studies covered drone applications in a general context, without explicitly distinguishing between outdoor and indoor use cases. Yet, indoor and outdoor drones exhibit significant disparities in design factors [25] including sizes, capabilities, costs, etc. As a result, they generate distinct levels of noise, entail diverse functional needs, and are suited to different scenarios. For example, a large-sized delivery drone can transport heavy goods, but it generates a high volume of noise that is unacceptable for indoor use. Conversely, a small drone emits less noise [38] and is more agile, making it better suited for use within homes, but its limited size restricts its load-carrying ability. As a result, the diversity of indoor and outdoor drones naturally gives rise to a wide range of interaction possibilities and challenges involving humans.

Notably, the majority of empirical research on HDI had their experimental setup in an indoor environment due to practical reasons considering complexity and safety risk [70], including being reliant on indoor hardware positioning systems, or constrained by ethical concerns of flying drones outdoors [43]. These studies generally did not specify whether their drones were intended for indoor or outdoor use, some even explicitly situated that the drones they studied were for outdoor applications (e.g., [31, 55]). While these previous HDI studies have been inspiring and have contributed to bringing more attention to drones and a better understanding of HDI at a general level, research explicitly targeting indoor HDI (e.g., [60, 65]) is still relatively scarce. In the following subsection, we argue for the necessity of exploring HDI within the context of indoor applications specifically.

2.2 Use Cases of Indoor Drones: Current State and Prospects

In the current commercial landscape, indoor drones have started garnering attention. The realm of indoor drones with automated tasks has been extensively investigated. Notably, Amazon showcased a demonstration featuring indoor drones surveilling homes in the absence of occupants [61]. Nevertheless, in these scenarios, the indoor drones operate autonomously, and there are no direct close-range interactions with users. Companies such as Indoor Robotics [47], FIXAR [18], and Flyability [19], are marketing autonomous indoor drones tailored for monitoring and inspection across diverse settings such as offices, data centres, warehouses, and malls. Crazyflie nano-quadrotors [11] were used by ETH Zürich as a tool to empower students to acquire firsthand lab experience by integrating these drones and applying theoretical knowledge [74]. Chinese startup Ryze Technology has introduced drones suitable for indoor flight, catering to both coding education for children and adults [58]. Moreover, toy manufacturers such as Silverlit [53] and Jianjian Technology [57] offer an array of toy drones, encompassing indoor helicopters and quadcopters tailored for indoor amusement. Nevertheless, the feedback from users engaging with indoor drones in these scenarios remains relatively unexplored, and there exists a limited understanding of user perceptions during utilization. This knowledge gap calls for comprehensive research to explore the experiential aspects as indoor drones become increasingly commonplace.

Despite most HDI research did not situate for indoor applications, we found some inspiring works that offer insights into the potential of indoor drones. The following mentioned literature may be applicable to indoor use context. The emergence of social drones in education holds promise, as drones have the potential to introduce innovative learning methods [43]. Research has delved into the possibilities and scenarios of integrating drones into educational settings, including their use in teaching science, technology, engineering, and mathematics (STEM) [59, 64], as well as instructing people to exercise at home [68]. Kim et al. claimed that people wanted their drone to work as a pet companion [35], and interacting with a pet has been found to be a frequent metaphor in studies on human-drone interaction [8]. User requirements and the design space of companion drones were investigated, indicating that participants favoured the idea of a drone companion in a home environment, and perceived it as a tool with both social and task-oriented attributes [32]. In another noteworthy development, Fuhrman et al. [20] introduced an indoor office drone assistant designed to perform errands and simple tasks within a laboratory setting, operating through verbal instructions and interactions with humans in the space. Additionally, small drones have been explored as indoor spatial search assistants [60].

Given these technological advances, early drone research prototyped various functionalities and interactions. For example, outdoor "free-floating public displays" as in Midair Displays [51], and soon thereafter, indoor "interactive real reality 3D displays" as in BitDrones [22, 48]. Drones were also studied for their capacity to provide navigational cues. For example, Huppert et al. investigated using drones to guide blind or visually impaired users [28] while Soto and Funk investigated the social acceptability of such drone-based guidance [3]. Other studies investigated natural interaction patterns with drones [8] or how interaction with a drone affects users' feelings, for example when domesticating a pet drone [66]. While these studies had a clear human-centered focus and provided novel, significant contributions to HCI, they mostly report on findings from a single user study, typically with a fixed setup and without differentiating factors that could help understand levels of user experience. This makes it difficult to compare across findings and to estimate the impact a function can have when targeting a specific user experience. Yet, previous studies have pointed out the necessity of exploring and identifying the potential functionalities and usage scenarios of indoor flying robots [65]. We find a notable scarcity of systematically conducted empirical studies exploring the potential applications of indoor drones. Our paper addresses this research gap.

2.3 Proxemics and Factors May Influence Perceptions on Drones

Proxemics examines how humans utilize the space between themselves and others during interactions and various activities [49]. It is notably crucial in the design of social drones [5]. Hall [24] introduced a framework that categorises interpersonal distances into four zones: intimate (up to 46cm), personal (46cm to 122cm), social (122cm to 366cm), and public (greater than 366cm). This framework is considered the most relevant aspect of Human-Robot Interaction (HRI) [23] and is widely applied in human-drone proxemics research. Studies by Wojciechowska et al. [70] and Bretin et al. [7] found that drone proximity is linked to increased stress and discomfort among participants, with closer approaches causing more discomfort.

Several factors can influence people's perceptions of drones, usually correlated to proxemics. Zhu et al. [72] found that participants' proxemic preferences were closely linked to their perception of drone predictability. Participants who perceived the drones as less threatening during the drone collision exposure tended to be more comfortable with drones flying closer, while others perceived greater distance as safer due to the drones' unpredictability. Wang et al. [65] investigated the correlation between sound conditions and proxemics and their effects on the perception of an indoor flying robot, and found that proxemics play a crucial role in how users perceive drones. Furthermore, the appearance of drones can significantly impact how people perceive and accept them at close range. Studies have revealed that adding protective features to drones instils a sense of safety, encouraging closer and more engaging interactions [1, 70]. Lieser et al. [40] demonstrated that people might accept the presence of small drones in close proximity, even if they have a mechanical appearance and lack social features. Yeh et al. [71] designed an oval-shaped social drone with a greeting voice and a cartoon face, which significantly reduced the minimum acceptable distance. Moreover, a previous study by E et al. [15]

highlighted how cultural differences could impact the proximity to drones that participants find comfortable.

However, it is worth noting that while spatial relations with outdoor drones are well-understood and mature [9], spatial relations with indoor drones pose distinct challenges. Drones operate in close proximity to users within indoor settings, subject to unique constraints. Furthermore, there is a notable dearth of research specifically exploring the relationships between proximity and the intended functions of indoor drones. Our study aims to address this research gap.

2.4 Drones' Flight Motions, Perceivable Actions, and Communicating Intended Function

Possible robot actions that users can readily perceive do not solely derive from their form factors or motions, with this challenge being particularly pronounced for flying robots. For example, a drone demonstrating a specific flight motion for educational purposes may not appear different from one taking a video acting the same motion. Flight motion was defined as a combination of trajectory, velocity, and orientation by Szafir et al.[56]. Their study underscored the pivotal role of robot motion in enabling effective human-robot interaction [56]. Despite this, the potential of utilizing flight motions as a communication method between humans and drones has only been briefly explored. Bevins and Duncan's [6] studies presented an iteratively refined understanding of how people interpreted the messages conveyed by drone flight paths and how they anticipated physical or emotional responses. Additionally, Sharma et al. [52] explored the utilization of drone paths for conveying affective information, indicating that the direct and indirect use of space, along with altering the system's speed, are two key elements that directly influence valence (positive or negative emotional experience). Studies by Lieser et al. [40] and Wojciechowska et.al [70] revealed that participants experienced increased anxiety when drones approached from behind, leading to a reduction in both comfort and perceived dominance. Furthermore, Wojciechowska et al. [70] found that, as the speed decreased, participants reported higher feelings of dominance and control, along with reduced arousal (intensity of emotion), and a straight trajectory was associated with increased calmness and reduced arousal during drone approaches.

While previous research indicated that flight motions can influence people's perceptions to some extent, they alone may not be sufficient to effectively allow users to perceive drones' actions. The incorporation of additional features is necessary to further support users. For instance, using light symbols to convey the intention of a drone [21] and using drone gestures [31] may be considered. Nevertheless, it is most often necessary to integrate an indoor drone into a wider context of use. This means that users will have clear expectations of the function or role of the robot. Research investigating how to convey the intended functions or roles of drones is currently missing. To explore the intended functions of indoor drones, we employed Research through Design (RtD) [73] and chose to apprise participants that the drone they encountered in the experiment had a specific purpose. Nevertheless, previous works inspired our scenario design and prototyping, see section 3.2.

3 METHODOLOGY AND EXPERIMENTS

In this section, we outline the methodology employed for our mixed-methods study and provide detailed information about our experiment.

3.1 Experimental Design

Our experimental design included two factors: 2 distance conditions (*near*, *far*) × 4 function conditions (*camera*, *education*, *pet*, *unknown*). The setup was a within-subjects approach, where each participant would take all eight conditions, one demonstration each, presented in randomized orders to avoid potential ordering effects. After each demonstration, participants filled in a short questionnaire. In addition, we performed a semi-structured interview after all eight demonstrations. Each session took around 45 to 65 minutes. All materials and procedures were carefully tested in a series of pilot tests.

Two distances were set as 60cm and 180cm, considering proxemics theory [23]. The rationale for choosing the functions is as follows: (i) Since outdoor aerial cameras are the most common drone application nowadays, it is worthwhile to explore the possibilities of using them as cameras indoors. (ii) The notion of using a drone as an educational tool has been proposed [43, 59, 64, 68] and even put into practice in the real world [74]. We aim to gain a deeper understanding of the user experience associated with this intriguing function. (iii) The idea of using robots as animal-like pets has long existed in technological imagination [63]. Previous studies have suggested the metaphor of a pet for drones [35, 38], but no known user study has physically evaluated the concept of a pet drone. By studying this function, we strive to contribute novel insights into users' experiences with pet drones. (iv) Lastly, we were also interested in understanding how people would react when encountering a drone without knowing its intended purpose.

3.2 Scenario Design and Prototyping

To contextualize the drone functions, we constructed concrete scenarios for each function, following a Research through Design (RtD) approach [73]. By evaluating the impact and performance of each artifact, the RtD approach empowers researchers to explore unanticipated effects and establish a framework for linking the broad aspects of the theory to a specific context of use [73]. We used storytelling to deliberately guide participants to immerse themselves in these scenarios. For our prototyping, we selected the Crazyflie 2.1 drone, which is small (suggested by [38, 40]) in size (92x92x29mm), and equipped with Lighthouse positioning systems from Bitcraze [11]. The flying trajectories and movements were meticulously designed, with each scenario having an identical flight time, and similar flying range and speed, all controlled by computer codes. These parameters were refined during pilot testing to ensure that the corresponding flying trajectories and movements facilitated the scenarios without introducing considerable disparities. To simulate a cozy home environment, we arranged home decorations and furniture in the lab, as depicted in Figure 1. The TV screen displayed relevant graphic icons to enhance the scenarios. The overarching scenario was that the experimenter and the participant were friends, with the experimenter acting as a host being visited by the participant. The host was using a flying robot at his home and engaged the participant to experience using the indoor drone. The participants could spend as much time with a scenario as they preferred. Each scenario included moments where participants actively had to interact with the flying robot in a way corresponding to the function being tested. The four scenarios studied are:

- ***Camera*** – The flying drone autonomously took photos and videos to capture moments. It took off, flew up and down to find a good angle, hovered to take pictures or film the participant and/or host, and then landed.
- ***Education*** – The host asked the participant to help with school assignments, starting with solving a basic trigonometric question. Based on the trigonometric solution, they programmed the drone to fly in circles. The host provided hints and showed answers in case the participant was unable to accomplish the tasks. The drone eventually took off, flew a few rounds of circles, and then landed. Thus, the drone was used as a tool to learn mathematics and computer science.
- ***Pet*** – The host informed the participant that the drone was his robotic pet. They both gently petted the drone, and then the robot took off and performed a dance. It initially rotated right to turn around, made a small jump, followed by rotating left to turn around again before landing.
- ***Unknown*** – The host told the participant that it would never be revealed what the drone was used for. The drone took off and performed a combination of movements from the other three scenarios.

3.3 Participants and Study Procedures

Sixty participants were involved in a laboratory-based experiment at the University of Luxembourg in Luxembourg (a small European country, surrounded by Belgium, France and Germany), following the approval of the University's Ethics Review Board. Participants were 34 self-identified females and 26 self-identified males, between the ages of 19 and 56 (M = 28.3, SD = 6.7). All were fluent in English. They were recruited through posters and posting on university bulletins, and sending invitations to friends and colleagues (snowball sampling). Participants received detailed information about the study procedures and provided informed consent before participating. Each received a 20-euro gift voucher for their involvement. Four participants' data were excluded from the later statistical analysis due to: one self-reporting anxiety issue, one hitting the drone by reaching out extensively while gesticulating with the hand which might cause an error on distance condition, and two giving non-differentiation ratings.

Communications during the experiment were in English. Participants sat in front of a long table with the experimenter sitting next to them. The table and chair were pre-located and marked to keep all participants at a similar distance from the drone. The drone took off from the two marked spots on the table, see Figure 1. Despite the small size of our drones, safety precautions were ensured. We pilot-tested the performances extensively to guarantee safe and highly controlled flying trajectories. In addition, each participant wore protective goggles and had a blanket at their disposal which they could toss at the drone at any time to stop the flight.

The experimenter introduced the study to each participant in detail before beginning the experiment. Then, each participant experienced all eight demonstrations and was asked to evaluate the drone on six measures in a questionnaire after each demonstration. Finally, after finishing all eight demonstrations the participants were interviewed regarding their experience, feelings and comments about the drone.

3.4 Measures

The questionnaire consisted of six items of semantic differentials on a 7-point scale (from 1 to 7) : Quiet/Noisy, Pleasant/Annoying, Useful/Useless, Relaxed/Stressful, Attractive/Unattractive, and Safe/Dangerous, with "1" representing an extremely positive impression and "7" representing an extremely negative impression (e.g., for Quiet/Noisy, "1" represents extremely quiet and "7" represents extremely noisy). The scale is exemplified as:

Quiet ○ ○ ○ ○ ○ ○ ○ Noisy

The ratings of Pleasant/Annoying, Useful/Useless, Attractive/Unattractive, and Safe/Dangerous were reversed for the statistical analysis. Partially inspired by previous studies (see [2] for reviews), we chose these measures for the following reasons: (i) Drone noise is a critical parameter for user experience. Quiet/Noisy was intended to examine the extent to which functions and distances could affect the **perceived noisiness** of the drone. (ii) Useful/Useless was selected to examine the **perceived usefulness** of the target function and was intended as the pragmatic evaluation of the drone. Usefulness of an interactive system is shaped by the context in which it is used and highly influences a user's overall evaluation of the system [42]. Usefulness has also been demonstrated as an important utilitarian factor while evaluating the user's acceptance of social robots [12]. (iii) **Perceived pleasantness** has been demonstrated to have an influence on usefulness, ease to use and enjoyment, and has been ascertained as an essential hedonic factor affecting HCI [12, 13]. (iv) **Perceived stress** has been found to be a predictor of user satisfaction, robot likability and future robot use [41]. (v) **Perceived attractiveness** was one of most commonly used perceptual assessment criteria in previous studies in user experience [39], and is considered as an indicator of robot likeability [4]. (vi) **Safety** is considered as the key issue in robot interacting with humans [4].

3.5 Interviews

The interviews were conducted in English using a semi-structured format. They were all administered and documented by the first author. Our questions addressed participants' preferences among these demonstrations (and the reasons for the preference), their experience of the drone at each distance and function respectively, reported feelings about the airflow and sound emitted by the drone, and suggestions for additional functions and the drone design. The interviewer asked follow-up questions when appropriate, and finally, the participants had the opportunity to add information they considered important and ask questions. All interviews were audio-recorded with the consent of the participants. Interview questions are listed in Appendix A.

4 DATA ANALYSIS AND RESULTS

This section presents the results of our mixed-methods study. We commence with the quantitative findings, followed by the qualitative results. Subsequently, we cross-reference both sets of results. For the sake of transparency and reproducibility, we report the software and packages used, as variations in software may affect results [33, 37].

4.1 Quantitative Data (Measures of Reported Perception) Analysis and Results

Data based on 56 participants was included in the statistical analysis. Statistical analyses were performed through R version 4.2.3 [45]. We visualized the original data of ratings on a 7-point scale using stacked bar charts to illustrate the distributions of participants' responses, see Figure 2. We first tested the assumptions of normality and sphericity for the data using the Shapiro-Wilk test and Mauchly's sphericity test respectively. Since both normality and sphericity assumptions were violated, we performed non-parametric analyses. Due to the multi-factorial design with repeated measures, we performed Aligned Rank Transform (ART) suggested by Wobbrock et al. [69] and applied the ART-C procedure proposed by Elkin et al. [16] for post-hoc analyses. ART and ART-C were performed using `art()` and `art.con()` from the `ARTool` package, which were developed by Elkin and Wobbrock and their colleagues [34]. For the post-hoc analysis, the Bonferroni correction was selected due to the within-subjects design [30]. The ART procedure will assess both main effects and interaction effects. In our study, the main effect of distance examines whether changes in distance impact participants' perception, irrespective of changes in functions. Similarly, the main effect of functions reveals the influence of functions on perception, independent of distance changes. The interaction between distance and functions examines whether their effects on participants' perceptions interact with each other, i.e., whether participants' perceptual differences between near and far distances vary based on different functions and vice versa. We decided to report partial eta squared as the estimate of effect size, denoted as η_p^2, which is interpreted as small effect size (0.01), medium effect size (0.06), or large effect size (0.14) [46]. We listed the detailed results for each measure one by one in the following subsections, namely: *perceived noisiness*, *perceived pleasantness*, *perceived usefulness*, *perceived stress*, *perceived attractiveness*, and *perceived safety*. We provide visualizations created by the `ggplot2` package [62] for each measure to support understanding of the results, see Figure 3.

4.1.1 *Perceived noisiness.*

Figure 3(a) shows the post-ART ranks of perceived noisiness at two distances with four intended functions. The main effect of distance (F (1, 55) = 38.91, $p < .001$, $\eta_p^2 = 0.092$) and functions (F (3, 165) = 16.62, $p < .001$, $\eta_p^2 = 0.115$) were statistically significant. The interaction effect did not reach a significant level (F (3, 165) = 1.51, p = .211, $\eta_p^2 = 0.012$). For post-hoc analysis with Bonferroni correction of main effects, participants' perceived noisiness when the drone was at *near* location (M = 251.21, SE = 13.31) was significantly higher than *far* location (M = 197.79, SE = 13.31), $p < .001$. Participants' perceived noise of *education* function (M = 173.13, SE = 14.58) was significantly lower than *camera* function (M = 246.26, SE = 14.48), $p < .001$, *pet* function (M = 243.98, SE = 14.48), $p < .001$, and *unknown* function (M = 234.64, SE = 14.48), $p < .001$.

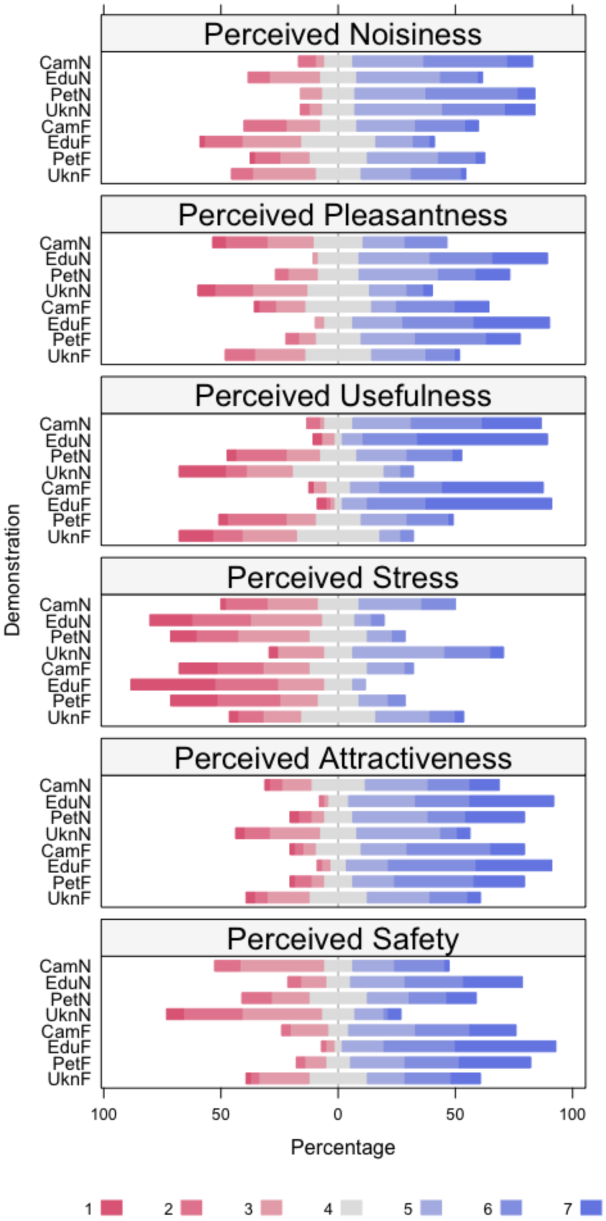

Figure 2: Stacked bar plots of participants' responses. N = *near*; F = *far*; Cam = *camera*; Edu = *education*; Pet = *pet*; Ukn = *unknown*.

4.1.2 *Perceived pleasantness.*

Figure 3(b) shows the post-ART ranks of perceived pleasantness at two distances with four intended functions. The main effects of distance (F (1, 55) = 24.18, $p < .001$, $\eta_p^2 = 0.059$) and functions (F (3, 165) = 52.87, $p < .001$, $\eta_p^2 = 0.292$)

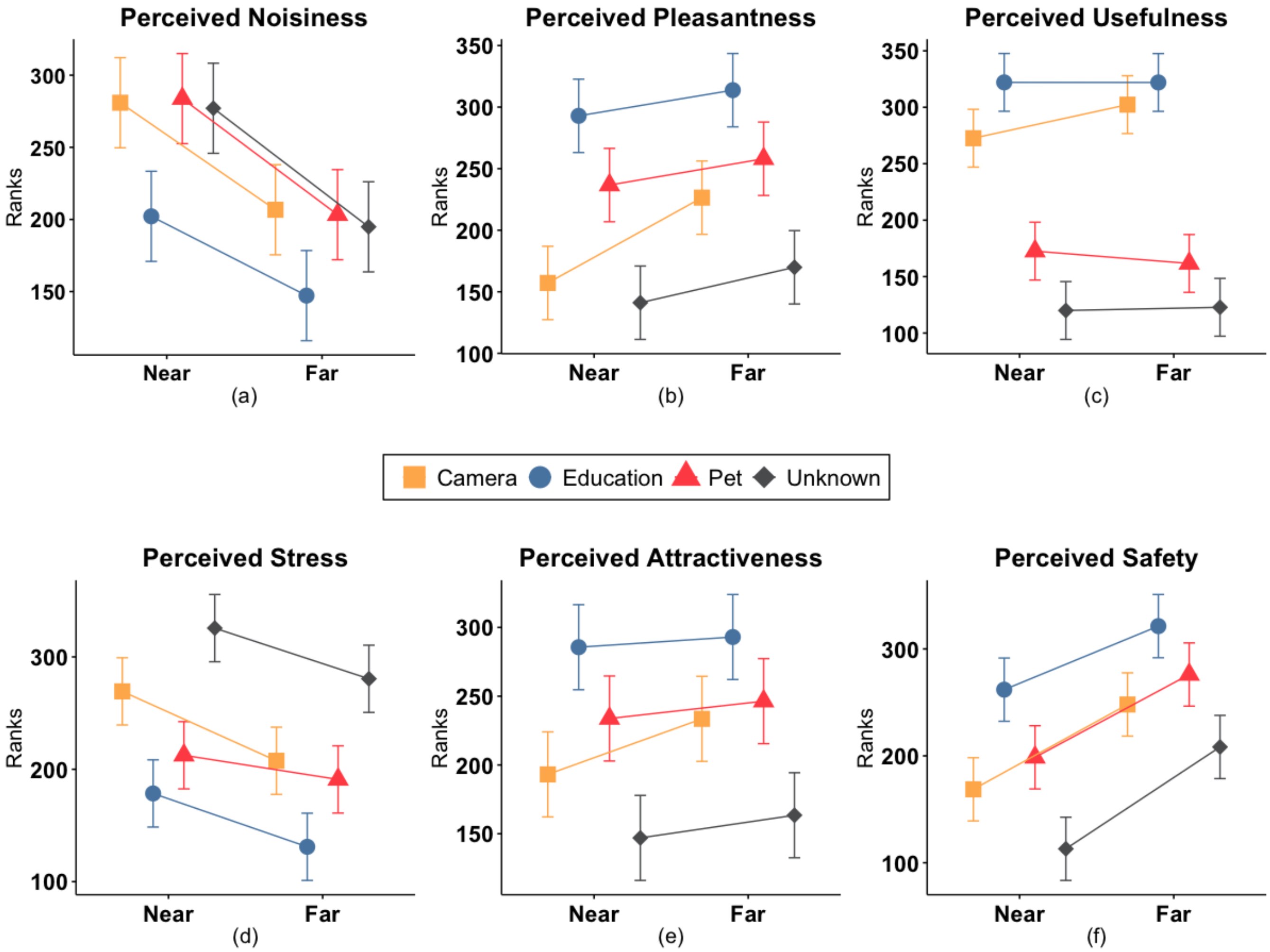

Figure 3: Interaction plots of four functions by two distances on six measures, with error bars (95% confidence interval), based on the data transformed by ART.

were statistically significant. The interaction effect was not significant (F (3, 165) = 1.61, p = .187, $\eta_p^2 = 0.012$). For post-hoc analysis with Bonferroni correction of main effects, participants' perceived pleasantness when the drone was at *near* location (M = 199.65, SE = 11.76) was significantly lower than *far* location (M = 249.35, SE = 11.76), p < .001. Participants' perceived pleasantness of *education* function (M = 306.00, SE = 12.54) was significantly higher than *camera* function (M = 190.37, SE = 14.48), p < .001, *pet* function (M = 248.30, SE = 14.48), p < .001, and *unknown* function (M = 153.34 SE = 14.48), p < .001; participants' perceived pleasantness of *pet* function (M = 248.30, SE = 14.48) was significantly higher than *camera* function (M = 190.37, SE = 14.48), p < .001, and *unknown* function (M = 153.34, SE = 14.48), p < .001; and participants' perceived pleasantness of *camera* function (M = 190.37, SE = 14.48) was significantly higher than *unknown* function (M = 153.34 SE = 14.48), p = .028.

4.1.3 ***Perceived usefulness.***

Figure 3(c) shows the post-ART ranks of perceived usefulness at two distances with four intended functions. The main effect of distance was not statistically significant (F (1, 55) = 1.76, p = .186, $\eta_p^2 = 0.005$). The main effect of functions was statistically significant (F (3, 165) = 147.39, p < .001, $\eta_p^2 = 0.517$). The interaction effect was not significant (F (3, 165) = 1.38, p = .249, $\eta_p^2 = 0.010$). For post-hoc analysis with Bonferroni correction of main effects, participants' perceived usefulness of *education* function (M = 324.61, SE = 10.21) was significantly higher than *camera* function (M = 286.74, SE = 10.21), p = .008, *pet* function (M = 165.95, SE = 10.21), p < .001, and *unknown* function (M = 120.71, SE = 10.21), p < .001; participants' perceived usefulness of *camera* function (M = 286.74, SE = 10.21) was significantly higher than *pet* function (M = 165.95, SE = 10.21), p < .001, and *unknown* function (M = 120.71 SE = 10.21), p < .001; participants' perceived pleasantness of *pet* function (M = 165.95, SE = 10.21) was significantly higher than *unknown* function (M = 120.71 SE = 10.21), p < .001.

4.1.4 ***Perceived stress.*** Figure 3(d) shows the post-ART ranks of perceived stress at two distances with four intended functions. The main effects of distance (F (1, 55) = 13.79, p < .001, η_P^2 = 0.035) and functions (F (3, 165) = 44.81, p < .001, η_P^2 = 0.259) were statistically significant. The interaction effect was not significant (F (3, 165) = 0.645, p = .587, η_P^2 = 0.005). For post-hoc analysis with Bonferroni correction of main effects, participants' perceived stress when the drone was at *near* location (M = 244.18, SE = 11.24) was significantly higher than *far* location (M = 204.82, SE = 11.24), p < .001. Participants' perceived stress of *unkown* function (M = 305.70, SE = 12.37) was significantly higher than *camera* function (M = 239.16, SE = 12.37), p < .001, *education* function (M = 152.77, SE = 12.37), p < .001, and *pet* function (M = 200.38, SE = 12.37), p < .001; participants' perceived stress of *camera* function (M = 239.16, SE = 12.37) was significantly higher than *education* function (M = 152.77, SE = 12.37), p < .001, and *pet* function (M = 200.38, SE = 12.37), p = .029; participants' perceived pleasantness of *pet* function (M = 200.38, SE = 12.37) was significantly higher than *education* function (M = 152.77, SE = 12.37), p = .003.

4.1.5 ***Perceived attractiveness.*** Figure 3(e) shows the post-ART ranks of perceived attractiveness at two distances with four intended functions. The main effect of distance (F (1, 55) = 4.74, p = .030, η_P^2 = 0.012) and functions (F (3, 165) = 35.28, p < .001, η_P^2 = 0.216) was statistically significant. The interaction effect was not significant (F (3, 165) = 0.76, p = .519, η_P^2 = 0.006). For post-hoc analysis with Bonferroni correction of main effects, participants' perceived attractiveness when the drone was at *near* location (M = 213.31, SE = 11.86) was significantly lower than *far* location (M = 235.69, SE = 11.86), p = .030. Participants' perceived attractiveness of *education* function (M = 291.00, SE = 12.81) was significantly higher than *camera* function (M = 212.32, SE = 12.81), p < .001, *pet* function (M = 240.61, SE = 12.81), p = .002, and *unknown* function (M = 154.07, SE = 12.81), p < .001; participants' perceived attractiveness of *unkonwn* function (M = 154.07, SE = 12.81) was significantly lower than *camera* function (M = 212.32, SE = 12.81), p < .001, and *pet* function (M = 240.61, SE = 12.81), p < .001.

4.1.6 ***Perceived safety.*** Figure 3(f) shows the post-ART ranks of perceived safety at two distances with four intended functions. The main effect of distance (F (1, 55) = 88.34, p < .001, η_P^2 = 0.187) and functions (F (3, 165) = 45.11, p < .001, η_P^2 = 0.260) was statistically significant. The interaction effect was not statistically significant (F (3, 165) = 1.65, p = .177, η_P^2 = 0.013). For post-hoc analysis with Bonferroni correction of main effects, participants' perceived safety when the drone was at *near* location (M = 180.64, SE = 11.68) was significantly lower than *far* location (M = 268.36, SE = 11.68), p < .001. Participants' perceived safety of *education* function (M = 298.68, SE = 12.98) was significantly higher than *camera* function (M = 207.65, SE = 12.98), p < .001, *pet* function (M = 238.16, SE = 12.98), p < .001, and *unknown* function (M = 153.51, SE = 12.98), p < .001; participants' perceived attractiveness of *unkonwn* function (M = 153.51, SE = 12.98) was significantly lower than *camera* function (M = 207.65, SE = 12.98), p < .001, and *pet* function (M = 238.16, SE = 12.98), p < .001.

4.2 Qualitative Data (Interviews) Analysis and Results

We used MacWhisper to automatically transcribe the audio recordings. Subsequently, the second author verified the accuracy of the transcriptions by cross-referencing them with the original audio recordings, fixing potential inconsistencies in the transcripts. Four researchers conducted a thematic analysis of interview transcripts [10], using MAXQDA2022 for coding and analysis [36]. Initially, we familiarized ourselves with the transcripts and took notes in the process. Through two discussions, we crafted the initial code system by synthesizing research memos, key concepts, and interview notes. Each of the four researchers subsequently independently coded the same eight transcripts with the initial code system. Following this, we conducted another coding meeting to refine and consolidate our code system, merging closely related codes. In the next stage, each researcher coded an additional 12 interview transcripts with the new code system. To ensure rigor and maintain consistency, the coded transcripts produced by each author underwent a thorough review by another researcher. Upon completing the coding and reviewing process, we merged the coded scripts, removing any duplicated codes. A researcher who did not participate in the initial coding process quality-checked the coded transcripts by randomly verifying three full transcripts and their coding. Disagreements were discussed to achieve consensus. In the following, we will report the codes by structuring them along the intended functions to allow for a better comparison of our quantitative and qualitative results. Afterward, we will comment on general expectations and ideas articulated by the participants.

The *education* demonstration was the favorite among 64% participants (N=36). The drone was seen as a way to make learning more interactive and interesting for these participants. 30% of the participants (N=17) mentioned the *camera* as their favorite, as it provided different angles and a better overview in creating photos and videos. Participants used words such as "useful", "pleasant", "safe", "visual", "exciting", and "happy" to describe their favorite demonstrations. In contrast, 59% of participants (N=33) disliked the *unknown* demonstration, particularly when the drone was close to the person. The *pet* demonstration was also reviewed as being less interesting or weird by 20% of participants (N=11). They found it difficult to perceive the drone as a pet due to its appearance and lack of meaningful interaction. Participants employed terms such as "annoying", "uncomfortable", "nervous", "suspicious", "stressful", "intimidated", "scared", "unpredictable", and "intrusive" to describe their dislikes.

4.2.1 ***Education: motivating and tangible learning, sense of accomplishment, and ideas for further engaging in drone-based learning.*** The vast majority of the participants found the drone quite nice and useful in the *education* demonstration. Notably, they perceived the drone as less noisy or distracting because they were focusing on the demonstration. As P25 said, "The noise does not influence much because my mind concentrates on thinking and observation." This indicated the drone could attract attention and engage people to learn. Most participants mentioned the drone could display abstract concepts in a tangible way and link theories to real-world applications, providing an "impressive", "fascinating", "enriching", and "pleasant" learning experience that helped them learn better. P28 stated, "The actual movement of the robot in a circle gives you a sense of realistic tangible result of a mathematical exercise. Such realistic, tangible exercises will imprint more in my memory." P59 said, "Having a real application and thinking about how to use this equation to have a result with the robot made me happier with the education process that I went through. So I felt like I could do something with the science."

Besides the experiential learning, many participants stressed their excitement and a sense of satisfaction. "Even if it was a fake situation, you did the programming, and I just saw the circle [the robot was flying], I was so proud... it would give a lot of satisfaction" (P27). "The fact of seeing it doing a circle is like how you say 'une récompense' in French. It's like a gift because it works" (P42). Some noted the drone could help people build "more interest for technology and science" (P4) and motivate them to learn "maths" and "programming" (P36). Some emphasized that they learned new knowledge from the demonstration. "It's very interesting for me because I now know how it works" (P1); and in P59's case, "I never thought about how can I program a robot to make a simple circle from this [trigonometric] equation. Never got that link before today."

Furthermore, participants suggested improvements for the flying robot as an educational tool. Several desired more complex drone flight motions in more 3-dimensional trajectories for more applications, whilst some demanded highlighted trajectories. "Maybe the drone can produce a color with its movement, so I can see, or line or laser, whatever it can, make it clear so I can follow" (P34). P8, P34, and P50 suggested having a projector on the drone for better visualization, and P54 suggested combining AR goggles for the same purpose. Moreover, several expressed safety concerns due to the likely trial and error during the learning process. As P22 put, "If I didn't program it right or if I messed up or something, that it would spin in a random way or maybe hit me." And P9 suggested, "a back system running in the background certifying and assuring that the drone wouldn't hurt anyone close, even if the user implemented a mistaken algorithm". For participants who mentioned they were not interested in STEM, they suggested exploring educational drones for subjects like art and literature.

4.2.2 ***Camera: useful and familiar, but annoying, with concerns about data protection, privacy.*** The majority of the participants viewed drone as *camera* relatively useful. "It offers very cinematic or a special kind of video that can be posted on social media" (P11). Participants specifically highlighted the drone's autonomous capabilities, with P15 stating, "What I appreciated in this scenario is the autonomous factor of it flying and taking off some videos and pictures." Further, they emphasized the drone's capacity to capture wider frames compared to regular cameras, as articulated by P8, "the recording [will be] better if it's a bit further away, you can put a whole group on the camera." This preference for the *camera* drone could stem from their personal experiences, as 13 out of 56 participants mentioned their familiarity with using drones as cameras. P18 shared, "I thought this was cool because that is the most application I have seen for outdoor drones. And I think it is nice for the photos."

Nevertheless, several participants expressed discomfort with the idea of a robot flying around during social gatherings, using descriptions such as "annoying", "disturbing", and "distracting". For instance, P6 presented a scenario, "When we have a good conversation or something, and then the drone is interrupting our talk, taking some pictures and being so close, I don't like that." Similarly, P7 voiced, "This is a big room, but still, having a drone flying around would be quite annoying." Surprisingly, 13 participants raised safety concerns related to the *camera* drone when used indoors. For example, P49 expressed apprehensions about the drone potentially colliding with people, saying, "I would be afraid that it collapses people. I don't know if it detects people or walls close to it or if it has a predetermined path to fly. I would feel less safe in that." This concern can be prevalent in social settings, where attention is divided and not exclusively focused on the drone. Furthermore, a group of participants expressed concerns over privacy invasion when the drone was used as *camera*. P30 voiced this unease, stating, "It feels unsafe. If we are with friends, it captures everything that we say, or we do." These apprehensions extended beyond the act of capturing media to encompass how the data would be utilized. Participants were wary that this feature might breach their personal privacy and mentioned the General Data Protection Regulation (GDPR) [17]. As exemplified by P43, "What do they do with all the pictures? Why do they do that? I don't want that." Similarly, P48 put, "I am a little concerned about the data protection and safety issues. I don't know what kind of data collection systems are in there or if they are safe. You do not know how the voice recordings, photos, pictures, or videos could be collected and packed."

Notably, several participants elaborated on the adaptability of *camera* drone in social events and compared its mechanical and sentient qualities to cameras with tripods. "The drone should be partyish itself. Having fun colors and more blinking lights here and there. In a relaxing environment, it would be fun to be able to draw something on it, like a smiley face" (P46). Further, P58 elaborated on the mechanical and sentient qualities of the *camera* drone, "You are saving the time for setting up a tripod. It also takes a more lively photo than a camera or a tripod would do, which is like a photographer. You feel more comfortable because it is a drone. When a photographer takes a photo, you have to look a certain way, or you are kind of thrown off by a human being being behind the camera, and they are judging the way you look and behave, whereas, with a drone, you can do whatever."

4.2.3 ***Pet: pleasant, but useless, lack of emotional bonds, feeling not alive, rather a toy.*** The majority of participants exhibited a tendency to liken the *pet* drone to a living creature. During the demonstration, around one-third of the participants visualized the drone as an actual animal. Various animal comparisons emerged, including "the paralyzed bird in the museums" (P50), "dragonfly" (P36), and "chameleon" (P44). Several participants conveyed a positive perception of the *pet* drone, utilizing terms like "cute", "comforting", and "cool" to characterize it. For example, P40 mentioned that the "tuk tuk tuk" sound generated by the drone made him feel lively, equating it to something charming. Further, a few participants pointed out the advantages of a *pet* drone as an alternative to traditional pets. P19 noted, "It could be useful for a lonely person who doesn't have time to have a pet because pets need a lot of time since you can just turn on the robot when needed." This echoes P53's remark that "(the drone) does not have any fur, so you don't need to take care of it, feed it, or walk it, and it does not stink."

However, nine participants considered the *pet* drone useless. P17 said, "I don't feel comfortable with the *pet* one. I think it is completely useless." P27 voiced, "It is okay to show it once, but as a *pet*, I don't find it pretty useful." Moreover, approximately three-quarters of the participants held the belief that the *pet* drone differed from a real pet. Several factors contributed to this perspective. The prevailing sentiment was that participants perceived the *pet* drone as lacking an emotional bond with them. P10 expressed, "It is difficult for me to accept it as something emotionally connected as a pet." Likewise, P4 compared the emotional connection with the drone to that with a pet, stating, "If I have a cat or dog, they can give me emotional feedback that will be much more important for me. The drone just listens to your command and follows your suggestion to do some movement or do some flight trajectory. But there is no emotional interaction between you and the drone." Finally, nine participants highlighted the drone's inanimate nature, making it difficult for them to regard it as a real pet. P28 said, "Pets are a living thing; I cannot have feelings with robots. They are not living things. They do not feel pain." Because of these factors, many of these participants felt more willing to portray the *pet* drone as a toy or entertainment tool rather than a pet. P31 contended, "It would be better to call it entertainment tools rather than pets. For example, some toys have remote controls for children and adults, and they enjoy controlling a flying object. They exist in the market. But why call them a pet? This does not make sense to me."

Participants further proposed a number of improvements to enhance the *pet* drone in terms of appearance, texture, and interaction. Nearly one-fifth of the participants proposed that the *pet* drone needed a "cover", such as fur, feathers, or interactive pictures. Texture was considered a crucial element in simulating the experience of petting an animal (P37), and interactive display could enhance the drone's appeal (P10). Specifically, P8 emphasized safety considerations, "The cover should be something soft that you can easily push away so that you cannot touch the robots. The rotors should be covered so you cannot put your finger inside." Four participants believed that more interactions between the *pet* drone and humans were necessary. P10 envisioned a more engaging experience with the drone flying at different heights, circling the user's body, and even laying on their shoulder. One participant, P7, suggested integrating AI into the *pet* drone, "If it had advanced artificial intelligence and could actually think exactly the same as an animal would, then it could be quite interesting."

4.2.4 ***Unknown: relationship, purpose, insecurity, and privacy.***

The acceptance of drones was influenced by the relationship between the operator and participant and the drone's intended purpose. Participants explained that their comfort levels were influenced by their relationship with the "operator". If they didn't know the operator, it could lead to feelings of stress and a preference for keeping a distance. Even when a friend operated the drone, *unknown* purposes could still make the movements and sound irritating. They emphasized the importance of clear communication and trust in drone operations. If they don't know the purpose of why this intelligent robot is near them, they "don't feel like in a safe position" (P37). As P58 said, "If you know that drones are used, for instance, by the police or by the government, and you know what to expect, even though you don't know who's flying the drone; but you still have like some sort of reassurance and safety." For some participants, when the purpose was *unknown* and entered personal space, it was regarded as "invading" (P57) and "suspicious" (P42). Interestingly, the relationship with the drone operator was much more prevalent in the *unknown* condition than in other conditions.

Regarding the drone itself, participants expressed feelings of insecurity and privacy concerns during *unknown* demonstrations, particularly when the drone was in close proximity. The physical closeness of the drone intensified their discomfort and safety concerns. Their worries encompassed physical harm, such as accidents involving contact with propellers or entanglement in hair (P54). As P60 said, "I don't know how it will move, and if it could fly into my face or if it could hurt me". Privacy and surveillance were focal concerns, as eleven participants expressed fear about being recorded without their consent. The presence of drones raised concerns due to perceived spatial intrusion (P22) and the potential violation of privacy (P34), verging on surveillance (P5). The lack of transparency in the drone's actions contributed to feelings of insecurity. As P5 commented, "Maybe it has a surveillance function. If it's recording me, then I don't know what that will be used". Participants felt anxious about the potential collection of their voice and visual data without informed consent, suspecting that such information could be misused for malicious purposes. They emphasized the importance of obtaining consent prior to recording or image capture.

Despite the frequent negative feelings, six participants indicated positive feelings, such as curiosity and interest, in *unknown* demonstrations. Participants found the aspect of unpredictability engaging, associating it with entertainment and excitement. In one instance, the movement pattern of the drone resembled calligraphy, sparking intrigue in P7. P18 and P36 found therapeutic value in observing the drone's slow and deliberate actions, suggesting a potentially calming influence. The novelty of the drones' activities in these scenarios was highlighted, with participants expressing fascination and a willingness to observe and engage with them. In summary, the *unknown* drone demonstrations evoked curiosity and captivation among several participants.

4.2.5 ***Participants' expectations.***

Participants specified a dozen improvements regarding the demonstrated functions. Some highlighted the safety features, such as adding frames around the propellers and integrating more sensors to avoid potential collisions. The demands for voice/gesture interactions, longer battery life, less noise, and more visible indicators of drone functionalities were mentioned in all demonstrations. Feedback for safety, personalization, communication, meaningful interaction, and autonomy of drones was evident in their feedback.

Participants brainstormed a variety of additional potential applications for indoor drones. These applications include enhancing home security through patrols, assisting with indoor tasks, and taking on roles similar to personal assistants. The suggested applications also involved indoor surveillance, delivering packages and messages, and even sources of light/sound/breeze/heat. Additionally, the conversation touched on using these drones for art exhibitions, monitoring air quality, and aiding with inventory checks. Participants also suggested using indoor drones for entertainment, medical procedures, search and rescue operations, and sporting competitions. The use of indoor drones for chores like cleaning and watching over pets was also discussed. Lastly, the concept of interacting with a drone swarm was introduced, pointing to innovative directions for future development. Overall, the brainstorming highlighted how adaptable and multifaceted indoor drones are, demonstrating their usefulness in various scenarios and applications.

4.3 Result Cross-Reference

We reviewed and compared both quantitative and qualitative results, finding that they resonate with and complement each other. Prominently, we noticed that participants frequently used the terms "useful"/"useless" and "pleasant"/"annoying" during the interview to describe their experiences with the drone functions. We therefore collated the measures of perceived *usefulness* and *pleasantness*, finding that their patterns closely aligned with the interview results. To visualize our findings, we created a scatter plot of post-ART rank means between perceived *usefulness* and *pleasantness*, as shown in Figure 4. Among the functions investigated, participants perceived the *camera* as useful but annoying, the *pet* as useless but pleasant, the *education* as both useful and pleasant, and the *unknown* as both useless and annoying. The qualitative insights elucidated the reasons behind the consistent quantitative patterns. We will further cross-reference these quantitative and qualitative results and discuss them in detail, integrating them into the upcoming Discussion section.

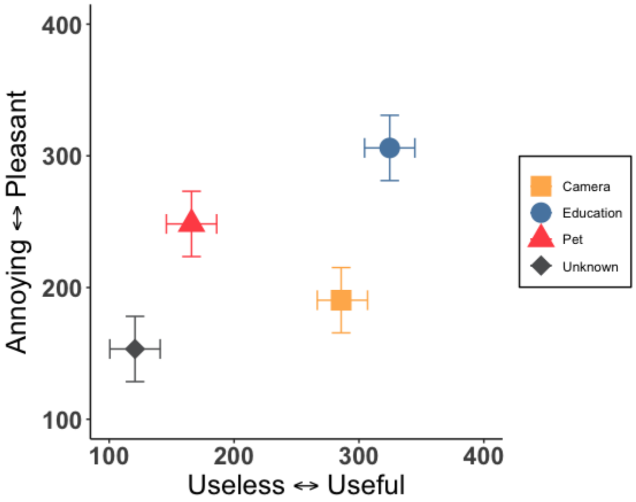

Figure 4: Scatter plot of post-ART rank means between perceived *usefulness* and *pleasantness*, with error bars (95% confidence interval).

5 DISCUSSION

In this section, we discuss the implications of our findings based on both quantitative evidence and qualitative insights.

5.1 The Necessity of and Approaches to Communicating Drone Functions

The *unknown* function received the worst ratings across perception measures among the studied function conditions, scoring the lowest in terms of *pleasantness*, *usefulness*, *attractiveness*, and *safety*, but registering the highest level of perceived *stress*. This aligns with participants' interview responses, as they expressed strong disapproval of the *unknown* function due to their irritation over the drone's unclear intent and their assumption that it might be used for disgraceful purposes. A few participants mentioned during the *unknown* demonstration that they even wanted to smash the drone down and leave the room immediately. To avert such issues, it is necessary for indoor drones to clearly convey their intended functions to individuals, particularly for secondary users or bystanders. This empirical finding echoes previous research [7, 65].

The most straightforward approach is to explicitly communicate a drone's purpose before and/or during its flying. For instance, a drone can be equipped with a loudspeaker to periodically announce its functions, or it can display a name tag with its role clearly written on it. In public areas, regulations could be implemented to require drones to convey their functions to people. However, enforcing such regulations for drones in home environments may be less practical or unnecessary, as primary users should already be aware of their drone's functions. An indirect approach, incorporating hints or cues to convey the functions of indoor drones, may be desirable. We recommend designing and incorporating drone covers, appearances, and relevant features (such as sound) based on their intended functions. As participants suggested, a *camera* drone wearing a party hat would be more appealing for use at house parties, making people more willing to be photographed. A *pet* drone could have fluffy fur or a soft cover for people to touch and play with, and adding cute sounds would make it more engaging.

5.2 The Criteria of Being Ideal Indoor Flying Robots

Education received the best ratings across all six perception measures among the studied function conditions, scoring the highest in terms of *pleasantness*, *usefulness*, *attractiveness*, and *safety* while registering the lowest level of perceived *noisiness* and *stress*. This is strongly supported by the interview data, where participants unanimously stated that they liked the *education* function the most. They believed it could motivate and engage them in learning, which they considered very useful. They were particularly amazed by the fact that the drone could display concepts in a tangible way and provide learning through experience. Participants also pointed out that they felt the *education* drone was distinctly less noisy and less distracting than the other three scenarios as they were concentrating on thinking and observing the drone. Both quantitative and qualitative results indicate that using indoor flying robots as an educational tool, especially for teaching STEM knowledge, can be compelling and promising.

The outstanding *education* function makes us ponder what are the criteria of being an ideal indoor drone. The concept of user experience can provide an explanation. According to Hassenzahl's model of user experience[26], pragmatic attributes emphasize functional efficiency and effectiveness, aiding users in task accomplishment, whereas hedonic attributes encompass emotional and aesthetic qualities, enriching users' enjoyment and satisfaction. In our experiment, participants' perceptions of *usefulness* can be associated with the pragmatic facets of the user experience, while the assessment of *pleasantness* and the idea of becoming more competent by learning with the drone align with the hedonic dimension. As shown in Figure 4, the *education* function excelled in both pragmatic and hedonic aspects. Consequently, it emerged as the function most favored by participants. Conversely, the *unknown* function, low in both pragmatic and hedonic measures, was the least-liked one. Moreover, participants found the *camera* function as high in pragmatic aspects but low in hedonic appeal, whereas the *pet* function exhibited precisely the opposite pattern. In addition, two focal topics voiced by the participants were related to drone noises and safety concerns. Participants expressed their repugnance of the noise generated by the drone, despite its compact size. This issue warrants improvement, especially for indoor flying robots. Furthermore, participants frequently expressed concerns about safety, highlighting the potential risks associated with drone use – they mentioned an *education* drone might malfunction due to incorrectly implemented code; a *camera* drone might collide with people when operated indoors. To address these concerns, practical measures such as the incorporation of preventive control algorithms (software), propeller guards/sensors (hardware) and maintaining an adequate distance from people should be implemented to ensure safety. Enhancing these two aspects primarily contributes to the pragmatic attributes of the user experience, ensuring efficient and safe drone operations. Additionally, there can be hedonic benefits as well, as these enhancements contribute to peace of mind and elicit a more positive emotional response. Hence, it is worthwhile to optimize both pragmatic and hedonic attributes, capitalizing on the strengths of various functions, improving drone noise levels, and ensuring safety, in order to achieve the ideal indoor flying robots.

5.3 Privacy Concerns and Transparent Technologies

While no significant interactions between functions and distances were found for all six measures, the interaction plot (see Figure 3) hinted at possible interactions. We acknowledge this as a limitation of non-parametric analysis, which typically has lower statistical power. Notably, we observed that the *camera* lines on the interaction plots were exceptional, especially in terms of perceived *pleasantness* and *stress* (see Figure 3(b)(d)). While the lines for the other three functions were visually more or less parallel, the *camera* lines appeared noticeably more oblique and nonparallel to the others. This indicates that the *camera* ratings had a considerable impact on the strength of the interactions between functions and distances.

Consistent with the measure findings, participants expressed that while they found the *camera* function to be highly useful, they also considered the *camera* drone to be quite annoying and stressful. They felt as though they were being watched and recorded, raising concerns about personal data privacy. For *unknown* conditions, participants had the most negative feelings. They unconsciously suspected the drone had a camera and was surreptitiously surveilling them. The inability to identify the owner of the drone and ascertain its intentions exacerbates these concerns, thereby posing challenges to the legitimate use of drones. Notably, participants referenced GDPR [17]. It is essential to recognize that this experiment was carried out in Europe, where individuals tend to exhibit heightened sensitivity to data privacy matters.

The data gathered by the drone, encompassing images and videos, is susceptible to potential misuse or mishandling. As the data is typically collected without people's consent, this can potentially infringe on their rights to control their own likeness. With the lack of clarity regarding data access, the management of the data collected also poses a challenge. In the event of a security breach or hacker attack, it could potentially lead to a severe privacy breach and the data collected without consent could fall into the wrong hands, armed with advanced AI and big data capabilities, putting individuals at risk of identity harassment, theft, or other criminal activities. Therefore, besides advocating for trustworthy AI, balancing the benefits of drone technology with respect for privacy is an ongoing challenge that requires careful consideration and appropriate safeguards. With the advent of increasingly sophisticated cyber threats, there is a rising need to establish stringent security protocols, privacy regulations and responsible drone operation practices to ensure the transparency of data collection and usage.

5.4 Robotic Care and Love?

In contrast to the *camera*, the *pet* drone was rated relatively useless but pleasant (see Figure 4). Despite participants claiming they found the *pet* drone not useful, they described it as "cute", "funny", and "interesting". They could recognize that it was performing a little dance. Participants mentioned that a robotic pet could offer the upsides of having an animal companion that people can play with while avoiding the downsides such as shedding, odors, fecal matter, the risk of being bitten, and so on. Nevertheless, many pointed out that they would rather refer to the drone as a toy or an entertainment tool than a pet, attributing this to its inanimate nature which made it difficult for them to form an emotional bond with it. Although previous research suggested that people were inclined to use a "pet" metaphor for interacting with drones [5, 8, 35], our findings clearly show that people do not prefer to use drones as pets. Instead, considering flying robots as toys or entertainment devices may be more appropriate in the current context.

Nevertheless, the conversations with participants have brought us to rethink the boundaries between living animals and non-living machines. With ongoing developments in AI, more advanced deep neural networks might enable robots to mimic animal behaviors at an indistinguishable level. Add to that the very realistic animal appearances and sounds, and one wonders if people would accept them as "living" pets. Moreover, the mimicry of animals can be extended to robots mimicking human characteristics and capabilities. In our study, P58 formulated that the slightly wonky flying *camera* drone made him feel it was something between a grounded tripod and a human photographer. What if flying robots become more intelligent, more social, and even more human-like? Could *camera* drones replace human photographers? Could *education* drones replace teachers? Could these robots provide care and love? How would we, as real humans, treat these human-ish robots? With technological advancement and societal demands, considering these philosophical questions and the relevant ethical implications becomes increasingly necessary.

5.5 *"Make Love, Not War"*

In the study context, we had the opportunity for casual conversations with many participants, all of whom expressed their appreciation for the experiment. Although these conversations were not recorded, participants gave their consent to use the content, and this content sheds light on potentially wider contexts of futurist HDI. Several participants mentioned that they had previously watched mind-blowing YouTube videos about indoor drone applications. On one side of the spectrum of fictitious HDI, one participant mentioned a video of "Dildo Drone" [14] where a flying robot offered hands-free masturbation for those who wanted to engage in self-pleasure while eating a burger and drinking a beer simultaneously [54]. We find the idea very humorous, but why not consider it? It is certainly a niche to investigate the possibility of intimacy and affection with flying robots. On the other side of the HDI spectrum, a couple of participants coincided to mention a video of "Slaughterbots" [67]. In this video, tiny drones employed AI and facial recognition to assassinate human targets indoors [50]. Participants commented that they had been frightened by the idea of this lethal autonomous weapon and claimed that the media had given them a stereotype of drones being used as weapons. However, our experiment altered their impression of flying robots. A participant with citizenship from a country currently undergoing war stated, "In my head, drones used to be military, they kill people. But your experiment changed my perspective. It's really eye-opening to me – they can actually be used for good things." Recalling these stories, we associate the 1960s slogan and advocate that flying robots should "*make love, not war*". As researchers, designers, and engineers, we should make responsible choices and intentionally help to build technologies to serve the goal of human flourishing, rather than the other way around. Investigating the potential functions of indoor drones is a vital step in this endeavor.

5.6 The Unsurprising and Surprising Findings, Originality and Novelty, and Summary

While the outcomes pertaining to participants' perceptions of the drone from the experiment may appear unsurprising to some readers, these results inherently align with logical expectations, affirming the study's methodological rigor. In addition, adhering to robust research methodology, our experiment design deliberately refrained from preemptively predicting outcomes. Consequently, the findings retain an element of unexpectedness and were surprising to us as authors in this regard. Concretely, it was surprising that the ratings for *education* largely surpassed the others, and we discovered this only after having conducted the experiment. Similar surprising findings emerged for the pleasant but useless *pet* and the useful but annoying *camera*, and so forth.

Since noise is a salient issue for drones interacting with humans, some might assume that perception measures on drones are ultimately linked to their perceived noise level. However, our results are surprising and show that this may not be the case. For example, in terms of the comparison between the *camera* and *pet*, as shown in Figure 3, their perceived noisiness was almost identical. However, they varied significantly across the other five measures, particularly displaying contrary patterns for their perceived pleasantness and usefulness. This indicates that perceived noise is not a decisive element in perceptions of drones. Particularly regarding the *pet* function, it was unexpected that our participants clearly disliked the "pet" metaphor, challenging the notion that people would prefer such a metaphor, as suggested by previous research [5, 8, 35], which lacked empirical validation. For the *education* function, despite participants' suggestions of adding displays and lights on drones, which resonated with previous research [22, 48, 51], we argue that our scenario design was novel. It combined previous ideas of using drones to demonstrate STEM models [64] and learn through experience. This provides empirical evidence supporting the idea that using drones to teach STEM is compelling and should be further explored. Along the same lines, empirical validation of these ostensibly "conventional" ideas remains imperative to substantiate prevailing assumptions, lest they remain speculative conjectures.

Furthermore, in terms of originality, this paper identifies the scarcity of systematic research on factors impacting user experience in interactions with drones, while also providing empirical validation of specific, novel prototypes. Our results unequivocally establish the necessity for systematic exploration, demonstrating the profound impact of function on user experience, coupled with factors like proxemics. As a result, our findings hold substantial potential to empower designers and researchers in creating drones by providing systematic insights into the intricate relationships among functions, proxemics, and drone characteristics.

In summary, it is crucial that indoor drones clearly communicate their intended functions to users to avoid negative impressions, and we have discussed various approaches to achieve this. Drawing on the concept of user experience, we explored the criteria for ideal indoor flying robots, emphasizing how both pragmatic and hedonic aspects need consideration. Our findings further revealed the fear of personal data breaches and cyber-attacks poses substantial barriers to the domestic adoption of flying robots, a concern that is increasingly pertinent in an era marked by advancements in the Internet of Things, cloud computing, and artificial intelligence. These technologies not only make machines "smarter" and more interconnected, they also heighten the need for stringent security measures. In response to such challenges, we advocate a design approach based upon transparency, trustworthiness, security, privacy, care, and the ethical deployment of flying robots in home environments.

6 LIMITATIONS AND FUTURE WORK

Although we recruited a large and diverse sample of users, this study did not differentiate users' backgrounds. However, as many participants pointed out, factors such as age group, occupation, cultural background, personal interests and preferences can significantly influence the user experience and perception. Moreover, the study was conducted within a household environment, but it did not account for other indoor settings, such as drones in public buildings. Furthermore, we cannot rule out that the engagement of our participants was identical for all functions (for example, because the perceived controllability of the flight might have been higher in the *education* function), although care was taken to keeping flight time strictly identical, not imposing any time limit for participants' interaction beyond this, and all functions were introduced in a scenario that involved active engagement with the flying robot. Additionally, we must acknowledge the potential impact of technical factors, including the integration of sensors, the battery's weight, and the computational power level, which may introduce biases, as exemplified by the potential increase in drone weight and noise, leading participants to perceive it as more dangerous. In addition, even in cases where the drone's primary function is evident, there remains a need for clearer communication regarding its behaviors and intentions when performing sub-tasks.

Regarding the contexts investigated in this study, there is still significant room for exploration of users' perceptions. More specifically, future research might investigate the integration of an actual camera into the ***camera*** drone, introducing the variance of the presence of an actual lens and extra weight, which might lead to a perception of increased discomfort. Addressing data privacy concerns is of utmost importance for the continued development of this drone use case. Furthermore, it is essential to conduct in-depth examinations and explorations of environmental factors, considering scenarios such as large gatherings (often characterized by noise and reduced privacy) versus quiet evenings at home (typically offering relative tranquility and increased privacy). The ***education*** drone in this study had certain limitations, including a lack of 3D interaction, limited diversity within STEM fields, constrained use of light and projection, and limited multi-modality. In the future, there could be opportunities to enhance the educational application by incorporating one or more of these features. Subsequent research can also explore how the use of drones can enhance learning effectiveness and efficiency, and how teachers integrate this novel tool into their curriculum. Regarding the ***pet*** drone application, incorporating features like fur, potential scents, establishing a specific body temperature, or introducing more complex pet-like behaviors fell beyond the scope of our current study, but would be worthwhile for future research. Additionally, exploring more context-specific applications, such as service drones for people with special needs, including the utilization of drones as guide dogs to employ sound cues for guiding those with visual impairments, presents a viable avenue for investigation. It is crucial to gain a deeper understanding of whether there is genuine demand for highly advanced AI-driven drones as pets. Furthermore, exploring the amalgamation of several of the features mentioned herein may be a promising avenue for future exploration.

While our research explored a wide range of potential uses for indoor drones, we chose to adopt an RtD approach, where the primary goal was not statistical generalizability but, rather, the emphasis was placed on the transferability and applicability of insights. In future work, an exploration of a broader spectrum of functions for indoor drones could be undertaken to expand upon our existing findings. Future research could delve into the individual drone use cases presented in this paper, tailoring the investigations to specific contexts and target audiences. For instance, these studies might focus on distinct demographic groups, including children, the elderly, and individuals with impairments, also various indoor environments, such as households, classrooms, malls and offices, in order to provide a more nuanced and detailed examination of the user experience within these specific contexts. Furthermore, it is worth noting that this study solely involved a single drone. In real-world social settings, individuals or friends may each have their own drones, and groups might engage with multiple drones concurrently. This opens up possibilities for exploring interactions with drone swarms, a scenario that warrants further investigation.

7 CONCLUSIONS

To our knowledge, this paper presents the first HCI study to explore how intended functions and proxemics may affect human perceptions of an indoor drone's *noisiness*, *pleasantness*, *usefulness*, *stress*, *attractiveness*, and *safety*. Participants (N=60) interacted with a real flying robot indoors and reported their experiences across four studied functions (*education*, *camera*, *pet*, and *unknown*) at two distances (*near*, *far*). They preferred the *education* drone the most, expressed concerns about their privacy after encountering the *camera* drone, considered the *pet* drone more as a toy, but reported the most negative experiences when the drone function was *unknown*. Both quantitative and qualitative results reveal that the intended functions of indoor drones may be a pivotal factor in impacting user experience, and thus are vital to consider for creating positive human-drone interactions. We derived recommendations and outlined potential use cases of indoor drones for further study. Despite the challenges, our work highlights the opportunities for future indoor flying robots to interact with humans. We advocate for the responsible use of drone technology for the greater good.

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A INTERVIEW QUESTIONS

We used the following guide of interview questions for our semi-structured interviews. After each question, we asked follow-up questions to collect reasons for participants' choices, ask for potential impacts of distance on participants' experiences, and paraphrased participants' answers to safeguard correct understanding.

Preferences: Among the eight demonstrations you have experienced:

- Is there any demonstration that you liked the most? And why?
- Is there any demonstration that you disliked the most? And why?
- Which demonstration did you have a special feeling about, besides the ones you mentioned? And why?

Systematic investigation of remaining functions: (*Ask this question until all functions get articulated by participants regarding their experience:)

- How was your experience with the {one function participants didn't yet articulate among: ***camera***, ***education***, ***pet***, ***unknown*** } function? And why?

Participants' general impressions of functions of indoor drones:

- Do you think these functions are useful? and Why?
- Are there any other functions you think would be suitable for indoor flying robot to have?
- Did you feel the airflow when the robot was flying? How did you feel about the airflow? Does the airflow have an impact on the intended functions? And why?

Invitation to make additional comments or ask remaining questions:

- Do you have any additional points that we did not discuss?