A Drone Nearly Hit Me! A Reflection on the Human Factors of Drone Collisions

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ABSTRACT

The use of multi-rotor drones has grown exponentially as a consumer product and in the commercial sector. The inescapable reality is that drones will become a ubiquitous part of society. One major obstacle to the mainstream acceptance of drones is the public perception of drones being dangerous or a safety hazard. This paper presents an investigation into the human factors toward potential drone collisions. The study included twenty participants who underwent a controlled drone collision exposure and a post-exposure interview. We propose a novel drone collision exposure involving a novel experimental setup simulating drone to human collisions safely. We found that all participants identified the drone's propellers as their primary concern, with the propeller's sound being the most threatening. Based on the participant feedback, we identified some concerns on a drone's unregulated aspects and outline common participant recommendations on drone regulations.

KEYWORDS

Human Factors, Multi-rotor Drones, Human Machine Interaction

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1 INTRODUCTION

In recent years the market for drones as an emerging technology has grown exponentially. According to the Goldman Sachs market report, [16], the drone market will be a 100 billion dollar market by the end of 2020 (70% Military and 30% Consumer and Commercial sector) with projections of the value tripling by the end of 2024. As the commercial drone sector grows, the inevitable outcome is the increased usage and presence of drones in populated urban areas. The heightened presence of drones will gradually transition drone encounters from an unusual sighting to becoming a mainstream part of society.

The relationship between humans and drones play a critical role in the acceptance and integration of drones into society [13]. Drone collisions is a primary concern of the general public because of notable incidences and a high potential for severe bodily harm or significant property damage [3, 19]. This reputation leads to distrust and opposition toward drone integration [13]. Other common factors that affect a person's acceptance of drones are privacy concerns [9, 10], and noise pollution [11]. This paper presents a study of 20 participants who experienced a controlled level of exposure to a drone collision (or near-collision) event. Based on this first-hand experience, the participants provided feedback through a face to face interview. The interview addresses the participant's key concerns when a drone flies in proximity to them and their opinions on the current state of drone presence in daily life. From these reflections, we hope to formulate an informed approach to integrating drones into society.

The main contributions of this paper are:

(1) A novel experiment design for exposing participants to drone collisions
(2) Interview data outlining the different aspects of concern toward drones collision exposure
(3) Suggestions on drone designs and regulations based on participant feedback.

2 BACKGROUND

2.1 Drone Incidents and Regulations

2.1.1 Significant Incidents. Drone-related incidents and other adverse events often shape the public perception of drones. The U.S. Federal Aviation Administration (FAA) has reported an increase in drone-related incidents in the past few years (2015-2017), with around 300-400 incidents recorded per year [2]. These incidents include drones colliding with people, property, and other aircraft (commercial airliners, hot air balloons, and helicopters). A notable incident is the 2016 alleged drone collision with a British plane, Airbus 320, at Heathrow Airport [7]. This incident was considered the first major drone-related incident in the U.K. and labelled drones

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as a risk to human life [7, 19]. This labelling played a part in the severity of the response during the Gatwick Airport incident in 2018. An alleged drone sighting caused a two-day closure of the airport resulting in over 1000 affected flights and two arrests (later considered wrongful arrests) [18]. The incident drew international attention and government regulatory bodies proactively instituting harsher restrictions on drone flights [14]. Another significant implication is the severe legal penalties with flying a drone within airport airspace to be considered a criminal offence with the maximum penalty of life imprisonment [6]. Other incidents such as the injury of the Australian triathlete by a drone in 2014 [4], and the numerous occasions of a drone breaching privacy laws [9, 10, 12] has caused a negative or cautious reputation to the ordinary citizen.

2.1.2 Government Regulation. The regulation of drones has posed a significant challenge to regulating bodies worldwide as drone technology is rapidly growing in popularity [13, 19]. This paper outlines the Australian regulatory body, known as the Civil Aviation Safety Authority (CASA), laws. CASA is one of the first regulatory bodies to regulate Unmanned Aerial Vehicles (UAV), or civil drones [19]. Drone operators in Australia are restricted to fly a drone at a minimum distance of 30m away from people, and drones cannot be flown in restricted air spaces (airports, emergencies, and helicopter landing pads).

One observation made by Wild et al. [19], was that the drone laws focus on regulating operator behaviour, with drone weight classes being the only drone-related restriction. Wild et al. [19], investigated 152 civil remotely piloted aircraft systems incidents between 2006-2015. The study concluded that most incidents tend to be due to technical failures, and drone regulatory bodies should consider drone technology rather than solely on operator behaviour [19]. Clarke and Roger [5] made a similar observation stating that many gaps in the law do not account for the range of drone technologies with varying risks to personal injury, invasion of privacy, and property damage during a crash.

2.2 Related Works

A variety of studies have investigated the human factors (the relationship between technology and the surrounding people) during drone flight in proximity to a person. Controlled exposure is essential when investigating human factors as most people are not regularly exposed to drones in their daily life. Abtahi et al. [1] investigated the drone propeller designs to find out if people feel that drones are safe to touch. The study used two drone designs, one with and another without propeller guards. Participants performed a variety of proximity interaction tasks with the drones, requiring physical touching of the drone. The study's participants were significantly less willing to touch an unguarded compared to the guarded "safe-to-touch" drone [1]. This result suggests that an unguarded propeller on a drone are more intimidating or threatening. A similar study performed by Yeh et al. [20] found that the appearance of safeness for a drone directly contributes to the acceptable distance between a person and a drone [20]. Our study explores the human response to being exposed to a drone flying in a more aggressive stance (flying towards collision). Our exposure method differs from previous studies as we remove the participant's agency (human prompts actions); instead, the drone actively elicits the participant's reaction.

3 METHODOLOGY

This experiment's primary goals are to investigate the key concerns people may have during drone flight and potential collisions. Then we assess how these concerns translate into general perceptions of drones in society. The experiment consisted of three stages, the pre-experiment (setup and questionnaire, 15-20 min), drone collision exposure (3x10 trials, 45 min), and post-experiment interview (20-30 min).

3.1 Drone Collision Exposure Protocol

The drone collision exposure provides valuable first-hand drone experience to the participant, which helps shape their general perceptions and opinion on drones. Most participants (18, 2 selected "monthly") reported to either "never" seen a drone before or on a "yearly" frequency suggesting that drones are an atypical occurrence. Figure 1A illustrates the experimental conditions for drone exposure. The participant would experience 30 trials of either a drone collision or a non-collision event (pseudo randomised 50-50 distribution). We chose two conditions to reduce the drone's predictability and prevent the participants from quickly acclimating to the collisions. During the experiment, the participant always stood (seated during rest) 0.3m behind a drone safety net. During each trial, the drone will take off 3m away from the net and fly toward the participant's upper body (shoulders to the head area). The non-collision condition involves the drone stopping at the 0.5-1m areas in front of the net (0.8-1.3m to the participant). The drone will not stop in the collision condition and will collide into the net. To ensure the participant's safety, we used motion capture to track the drone and the net's displacement. The participant is placed at 0.3m because the net's maximum displacement when the drone collides at full speed is around 0.25m. There were 3-minute rest breaks between every ten trials. The drone is manually controlled through the flight app (DJI Go) by the researcher, and the drone flew at 25km/h (max speed 50 km/h [8]).

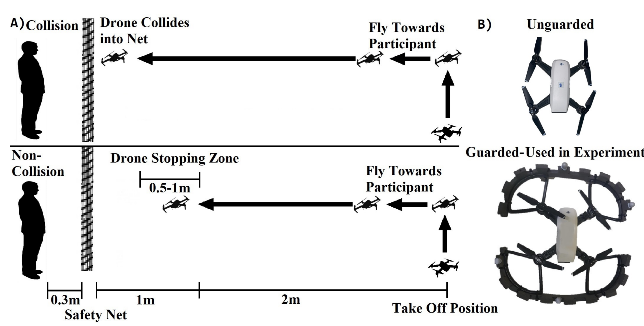

Figure 1: A) An outline of the two conditions (Collision vs Non-Collision) B) A regular DJI Spark and the experiment version.

3.1.1 Apparatus. We used a DJI Spark quadcopter for the collision exposure [8]. We chose this specific drone for its popularity in the consumer market (DJI reported to have 70% U.S. market shares in 2019 [17]). The DJI Spark can be considered a typical drone with recognisable features for the participants based on the popularity. The drone was modified with propeller guards (see Figure 1B) to protect both the participant and the drone (prevent propellers from getting caught in the net). The guards also act as mounts for motion capture reflective markers. Drone netting further protected the participant from the drone.

3.2 Questionnaires and Post Exposure Interview

3.2.1 Pre-Experiment Questionnaire. This questionnaire aimed to understand the participant's frequency of encountering a drone (rated from never, yearly, monthly, fortnightly, weekly, and daily) previous experiences with drones, including details if they piloted or had particular negative experiences.

3.2.2 Self Assessment Manikin (SAM)). At the end of each trial, the participant provided a verbal SAM rating (1-9) on their current arousal (mental activeness), valance (positive and negative emotions), and dominance (control of environment) level [15]. This questionnaire is a reliable indicator of the current emotional state of the participant during the two conditions. The SAM analysis involved separating the data into the two conditions and averaging across the participants. The difference between the two conditions was statistically tested using a One-Way ANOVA test (data was of Gaussian distribution) with the significance level (α) of 0.05 determining statistical significance.

3.2.3 Drone Threat Perception. The perception of danger is an essential factor in the acceptance of drones. During each rest break, the participants gave a rating (0 to 3) for their perceived danger level from the drone's visual, sound, and the two conditions. The questions evaluate each stage of drone flight, i.e. take off (seeing and hearing the propellers start), flight (seeing the drone fly towards them and increasing loudness of the drone), and general intimidation (loudness and visually dangerous). We averaged the participant ratings for visual and sound threats. Participants were identified as either visual or sound threat dominating with the minimum criteria of 25% difference between ratings (assigned both is below 25%). Like the SAM, the difference between the two conditions was statistically tested using a One-Way ANOVA test. The post-exposure interview further explored the perceived hazards during the drone flight. The first section aimed to identify if the participants felt acclimatised to the drone collision. The participant then held the drones (with and without propeller guards, see Figure 1B) and made observations on any design aspect they find notable or concerning.

3.2.4 Drones in Society. The second part of the post-exposure interview discussed with participants the implications as a consumer product. As a consumer, participants highlighted possible considerations with personal drone ownership and potential concerns with other surrounding people (e.g. neighbour) owning a drone. We also discussed the current drone regulation and whether they felt propeller guards were necessary. The participants provided design suggestions for potential propeller guards. We presented the participant with images of various drone propeller guard designs as stimulus material for propeller guard. The last part of the interview deals with the increasing occurrence of drones as commercial usage grows. The key discussion points were whether participants were comfortable with drones flying in their area and the appropriate level of covertness (or overtness) for a commercial drone. The research will then ask the participant to propose suggestions to potential regulation that they feel appropriate.

3.3 Participants

The experiment was conducted in person under strict hygiene guidelines (COVID-19 restrictions) and with the approval of the local institute's research ethics committee. All participants provided written informed consent for the experiment and video recorded interview. The study duration was 1 hour and 30 min and participants were compensated for their time. The participants were screened to be within the target age range (18-35 years) and possess the ability (language and mental) to complete the interview. We recruited 20 volunteering participants (7 females and 13 males), the mean age was 26, and the population variance was 4.13.

4 RESULTS

4.1 SAM

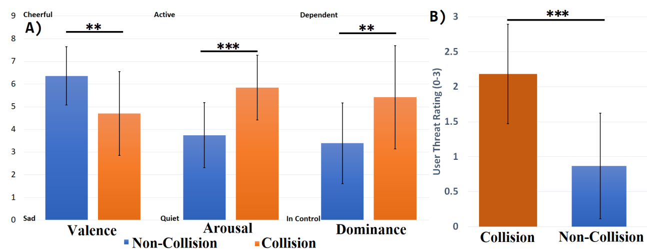

Figure 2: A) The SAM ratings for the experimental conditions. B) The threat rating (0-3) for the two conditions. *p<0.05 **p<0.01 ***p<0.001.

Figure 2A shows the SAM results for the two conditions. We found significant difference in the SAM rating for valence ($F(1,38)=10.46$, $p=0.0025$, and partial $\eta^2=0.22$), arousal ($F(1,38)=20.36$, $p<0.001$, and partial $\eta^2=0.35$), and dominance ($F(1,38)=9.39$, $p=0.0040$, and partial $\eta^2=0.2$). These results suggest that participants feel negative emotions (valence), heightened mentally active (arousal), and less in control (dominance) during drone collision.

4.2 Threat Perception

Figure 3A provides the distribution of participants based on which threat (visual, sound, or both) they rated highest during drone flight. 50% of the participants rated sound to be more threatening than the visual aspects, with only 25% who rated in reverse. 25% participants rated both as equally threatening. Figure 3B shows the minimum distances the participant is comfortable with the drone fly around them. Half of the participants responded with distances in the range of 0.5-2m, which was the non-collision condition's stopping distance. Interestingly, seven participants mentioned they were comfortable with the drone flying closer (at <0.5m) after the

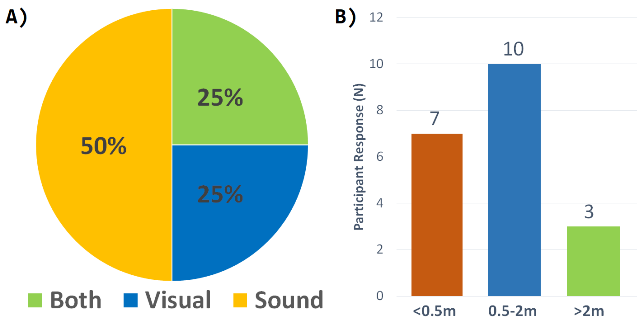

Figure 3: A) The distribution of visual and sound threat dominance for the participants (N=20). B) The minimum distances that participants felt comfortable for drone.

drone exposure. On the other hand, 3 participants reported they felt the drone should be further way at more than 2 metres. Figure 2B presents the user threat rating for the two conditions. The ratings show a significant increase (F(1,38)=30.60, p<0.001, and partial η^2=0.45) in user rating, which suggests that the participants felt more threatened when the drone collided with the net.

5 DISCUSSION

5.1 Perception of Threat

The SAM (Figure 2A) and user threat rating (Figure 2B) is a clear indication that the participants feel threatened by the drones during the drone collision exposure. The user ratings and the qualitative testimonies (from the interview) evaluate the specific aspects of drones that people found threatening. Fifteen participants felt more comfortable with the drone collision and less threatened after the 30 trials. Two common reasons were that the drone behaved predictably and trusted the drone netting to prevent harm. Conversely, five participants cited the drone's unpredictability as the main reason for not feeling comfortable with the drone. These participants felt that the drone still caught them off guard throughout the experiment. This finding is consistent with the minimum distance result (Figure 3B), where the participants who felt less threatened were more comfortable with the drone flying at a lower minimum distance. In contrast, the latter felt the drone should be further away (>2m). Based on this feedback, predictability is a critical factor in reducing the perception of danger and becoming more comfortable with drone flight.

While holding the drone (see Figure 1B, both guarded and unguarded), every participant mentioned the propellers (mostly when unguarded) as the most dangerous part of the drone. The main concerns with the propeller were the potential for personal injury. Ten participants rated (Figure 3A) the propeller's sound as most threatening, with six participants mentioning their surprise with the volume of noise. The dominance of sound is likely due to the propellers being less visible during flight. All the participants note the propeller as a visual threat when physically holding the drone (stationary). Another observation was the size and weight distribution of the drone. Interestingly, four participants noted that the guarded drone seemed larger in-flight (drone exposure) than a stationary held position. When observing the guarded drone's actual size, most participants felt more comfortable with the drone design. When holding the unguarded drone, eight participants noted they felt more danger because of the smaller (than the guarded) frame and centrally distributed weight. The participants reasoned that the drone would fly faster (greater force of impact) and be harder to avoid (less visible). On the other hand, five participants (seven participants did not note size as an issue) felt the smaller frame was less intimidating due to the perception of it being more similar to a toy drone.

Like previous studies, the shape and level of protection of the drone guards directly relate to the level of threat perceived by participants [1, 20]. These results stipulate that the propeller is the primary (agreed by all participants) threat perceived by participants because of the potential to inflict bodily harm. Stemming from this threat of bodily harm, the drone flight's predictability and shape (size and weight) will contribute to the perceived danger.

5.2 Integration to Society

Privacy and safety were the main highlighted concerns for drones operating in society. As a consumer, six participants expressed interest in owning a drone for personal use. The other participants did not feel the need for a personal drone and thought it would cause unnecessary trouble, such as being stolen or cause injury. Participants mentioned that as drone owners, the drone must be safe for others and preferred a small drone (similar size to DJI spark) with propeller guards and quieter motor/propellers. In the hypothetical scenario of a neighbour owning a drone, the participant's concerns shifted towards personal privacy and noise. Twelve participants were concerned with privacy, stating that the drones should not fly near them or their property (eight participants) and cannot record footage of them. Five participants raised concerns about the drone's loudness being a nuisance, with a participant suggesting time restrictions.

Participants were given a hypothetical of having multiple commercial drones operating around them with low presence (not distinctly visible and low noise) and not knowing the drone's specific purpose. Seventeen of the participants were uncomfortable with the prospect of incognito drones flying around them, citing issues with privacy and lack of safety if the drone malfunctions. Participants suggested that the drones should provide clear indications with light or sound to indicate the current status and mission. Another interesting statement is transparency; three participants highlighted that commercial drones should be marked and have the flight routes openly available to the public. The three participants who did not feel uncomfortable with commercial drones held the view of drone integration as being "inevitable" and that plenty of technologies such as planes and cars have become integrated into society. Two participants expressed that they trusted the commercial drones would be correctly regulated, and pilots would be accountable. Hence there was not a need to concern.

These views highlight the importance of accountability for drone owners and pilots. We suspect a fundamental reason for the privacy and safety concerns is the freedom possessed by drone pilots and the difficulty of intervening (or stopping) a drone in flight. The current drone laws are an excellent example of applying accountability to drone owners. However, the enforcement of drone designs and behaviour will help build societal trust in the reliability of the drone [5, 19].

5.3 Future of Drone Regulation

A promising remark when discussing drone regulations is the similarity between participants recommendations and the current drone regulations. Suggestions such as restricting drone flight (height and distance to people), pilots should be registered, and enforcement of drone sizes, are all currently regulated areas for drone owners.

One common observation is that the propellers of the drone were dangerous. Nineteen participants stated that drone guards should be mandatory. We presented the participant with three levels of protection found in various drone propeller guard designs and asked participants to highlight any feature they feel were necessary. Every participant agreed that the propeller guards would make drones safer. Thirteen participants felt that the guard should have mesh covers and a more extensive casing. One notable feature proposed (three participants) was that the guards should be child-safe in design as a drone can be attractive to a child's curiosity. These participants preferred designs with fewer gaps (mesh or encasing propellers) so that a child could not easily touch the drone's propellers. Most participants (fourteen) articulated that drones should have methods of signalling its identification, the direction of heading, and current status (alarm for when it is failing or a potential hazard). Some common suggestions were different sounds or light strobes (similar to planes) to signal the drone's presence and intention. Other participants also suggested drones should wirelessly transmit its identification and pilot ID to keep pilots accountable for their drone. The noise was another concern which participants felt should be regulated. One option suggested was to restrict drone motors (similar to vehicle engines) to quieter models or use commercially available noise reducing propellers. Another suggestion was to restrict the time of day a drone is permitted to fly (similar to residential noise restriction laws). The current state of drone laws does not cover the various designs and functionalities of drone models. In future, drone technologies should be regulated by the technical capabilities (signalling surrounding people and ability to be tracked and tracing) and potential hazards (propeller guards, battery flammability, noise, and child-safe).

6 LIMITATIONS AND FUTURE WORK

The sample size is the main limitation of this study. Recruiting more participants will strengthen the qualitative aspects of this study and allow different perspectives to arise. COVID-19 restrictions have greatly hindered our data collection, resulting in the current sample size. The findings presented indicate that drone collision exposure can successfully create a sense of threat from the drone. Potential future studies can further explore different demographics. The perception of drones also varies between cultures. For example, one participant felt that drones were inappropriate due to its military usage in certain countries. Recruiting different demographic groups may allow us to comprehend better how different cultures and experiences may affect society's drone usage.

7 CONCLUSION

A better understanding of drone flight's human factors will help make informed decisions when working towards a safe and ethical integration of drones in our society. This paper has presented the quantitative and qualitative findings of the drone collision experiment. We found that during a drone collision event, the propeller's sound is the main threat perceived by participants. Based on the post-exposure interview feedback, we suggest that future drone laws should consider imposing mandatory drone technology-oriented regulations rather than solely restricting the operator's behaviour.

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