# See it, hear it, feel it - Using virtual reality to investigate how people experience drones in different city areas

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## Abstract

In this paper a qualitative study with ten participants is presented that uses a passenger simulation to allow people to experience future drone use cases as realistically as possible. The simulation environment consists of head worn virtual reality glasses and a treadmill, which allows participants to walk through different urban sceneries and experience simulated drone traffic. Four different prototypic areas were modelled involving an industrial area, a main street in the city center, a residential area and a leisure zone with playground and a park. After each scenario participants rated their impression with help of a questionnaire and a semi-structured interview was conducted. The paper describes the immersive approach and reports on findings on how participants perceived drones in the chosen urban settings.

Keywords: social acceptance, simulation, virtual reality, drones, urban air mobility, qualitative study

## 1 Motivation

Urban air mobility (UAM) currently gains a lot of interest – from industry, from research, from politics and from society. With technological advancements of autonomous air vehicles and fully automated flight guidance, use cases like parcel delivery and passenger transport in populated environments are on the roadmap of research and development. In parallel with these technological and conceptual development, questions with regards to the social impact of this urban air mobility are getting more important – are these services accepted by people living in cities or the urban areas?

Social acceptance of UAM and drones therefor is investigated and is seen as one important parameter for the development of operational concepts. General models of technology acceptance claim that perceived benefits should outnumber perceived risks. Current studies clearly show that use cases with clear benefit for society are more likely accepted than commercial use cases. Nevertheless, when investigating perceived risks in more detail the challenge is that most people do not have experiences with that technology and these use cases and are not likely to rate specific concepts but can express general fears or attitudes towards technology.

Thus, the focus of this paper is on giving an overview and introducing our approach of using Virtual Reality (VR) to let people realistically experience future UAM use cases in different urban focus areas. For this purpose, we simulated four urban scenarios with drone traffic involving varying flight altitudes, starting and landing procedures, maneuvers and different drone types and use cases, for example large drones for passenger transport and small drones for hobby use. This way we could give participants a comprehensive impression of future drone traffic. Moreover, the used simulation allows to move around the virtual environment and to solve task by interacting with it. We describe the set-up for a qualitative VR acceptance study, providing an impression of the VR-simulation infrastructure and the workflow used to generate the simulation scenarios. Furthermore, we report findings of the qualitative study with regards to the experience of drones in different urban environments as well as concerns related to drones.

# 2 Theoretical Background

The social acceptability of drones is a research field of utmost interest and thus there are numerous studies, which explored the public opinion on drones as well as perceived risks and concerns about this new kind of air mobility. A recent survey investigated the acceptance of drone applications in highly urbanized environments and found, that drones for search and rescue missions, disaster management, monitoring or preserving certain areas have a high level of support. The lowest support has been identified for using drones for passenger transport, photography and videography [1]. Main concerns about drones that have been raised repeatedly in studies are violation of privacy, potential misuse for criminal actions and annoyance [1, 2]. Related to the perception of drones also the fear of a congested skies [2, 4] and noise pollution [3, 4] were found out as an important acceptance factor in recent research.

The context of use seems to play an important role, as surveys figured out, that the acceptability of drone flights is different in various urban areas. A study conducted by Tan detected the highest levels of acceptance for drones flying in industrial areas, whereas it is low for residential areas. As a possible explanation the study found that fears and concerns appeared to be a more salient factor for drone use in residential areas while perceived potential benefits could be a more critical consideration for non-residential areas. It needs to be kept in mind, that the survey was conducted in Singapore. Citizen might be more open for new advances and technologies compared to other countries [1]. A survey carried out in Germany came to similar results related to the context of drones use. As in the study of Tan, findings also indicated more approval for drone flights in industrial areas compared to residential areas and city centers. Moreover, participants of the study expressed a higher acceptance for drones overflying sparsely populated areas, whereas for heavily populated regions acceptance drops significantly [3]. This was also confirmed by the research of Yedavalli and Mooberry [4].

One challenge about studies in the field of drone acceptance is, that most people did not get in touch with drones yet, for examples having ever seen, heard or flown a drone [3]. Since the technology has not been widely introduced yet, research findings are probably limited to the imagination of participants [1]. Therefore, study designs providing an acoustic and/or visual impression of drone traffic are useful to measure annoyance or discomfort related to drones. There are already several studies using an experimental approach in such a way. A psychoacoustic investigation of small unmanned aerial systems (sUAS) conducted by Christian and Cabell compared drone noises to road vehicle noises. Their findings reveal, that the annoyance of drone noises is not only a matter of flight altitude, but rather may be influences by other flight characteristics, for example flight maneuvers. Furthermore, the findings of the study showed that there may be a systematic difference between the annoyance response generated by the noise of the sUAS and the road vehicles [5]. Further psychoacoustic studies reveal that in soundscapes with high road traffic noise, the presence of drone noise lead to small changes in the perceived loudness, annoyance and pleasantness, whereas in soundscapes with reduced road traffic noise it leads to higher changes [7]. Another study identified loudness, sharpness and fluctuation strength as significant factors that affect the annoyance of drone noises [8]. Research from Chang and Chetty and Aalmoes and Sieben not only focused on psychoacoustics, but also considered the visual perception of drones. In Chang and Chettys study, participants were observing real drones in a room. Aspects affecting annoyance identified in the experiment are noises, higher amounts of drones, color and shape of the drone and fast and jumpy movements [9]. The study of Aalmoes and Sieben investigated the visual and audio perception of drones by using a Virtual Reality simulation. Key findings are, that there are no differences in terms of annoyance between audio-visual and audio stimuli only. Results also did not show any difference in annoyance between a louder and a quieter street. Drones in a hovering mode were rated as more unpleasant than fly overs. Additionally, personal factors like preexisting attitudes towards drones have been shown to be significant predictor for general drone noise annoyance [6].

# 3 Research Question

The focus of this study is to investigate how drones are perceived in different urban environments, as surveys have identified urban setting or context as an important aspect related to public acceptance of drones [1, 3, 4]. Therefore, this study follows a qualitative approach, giving participants a realistic impression of future drone scenarios in different urban contexts and conducting interviews and providing questionnaires after each scenario. The scenarios involve an industrial area, a main street, a residential area and a park. This study wants to answer the following research questions:

1: How do people perceive drones in different urban areas?

2: Are there differences in people’s acceptance of drone flights in different urban areas?

# 4 Methodology

The study was conducted in the DLR MoSAIC-Lab (Modular and Scalable Application-Platform for Testing and Evaluating of ITS Components) in Brunswick. As part of the newest Vulnerable Road User (VRU) Simulator extension of the laboratory [10,11], it contains a state-of-the-art pedestrian simulator. Its main components are a motorized, omnidirectional treadmill (Omnifinity Omnideck) with a diameter of 4,70 m, a VR headset (HTC Vive Pro Eye) and corresponding controllers (s. Figure 1). All components connect and communicate through a powerful Virtual Reality (VR) PC. The treadmill receives the user's head position via the calibrated VR glasses and, if necessary, activates the surrounding, motorized roller segments which serve to progressively return the test subject back to the static center of the platform. This ensures that the test person never approaches the limits of the available physical space despite running. Without the limitation of physical space, the subject can move freely in the virtual world.

Figure 1: The MoSAIC-Lab Pedestrian Simulator

Designing the virtual environment, the challenge was to meet the requirements of the varied study design as well as the requirements of the VR pedestrian simulation which also has to take e.g. exhaustion and simulation sickness into consideration. Therefore, a complex environment with separated focus areas was created based on the outline of Cremlingen, a small city near Brunswick (s. Figure 2). The intention was to create small, self-contained sections which can be fully experienced during a time period of 15 minutes. The chosen areas are an industrial area (A), the city center (B), a part within the residential area (C) and a park (D).

The design process itself took place in Trian3DBuilder and Unreal Engine 4. To portray an elaborate and vivid environment a high-resolution road map of the German freeway A39 was combined with Open Street Map (OSM) Data of the city Cremlingen. For final polishing the scene then was exported to Unreal Engine 4. The framework was also used to implement the various scenarios such as (but not limited to) complex drone behaviour and user navigation trough interactive objects.


Figure 2: Focus areas in virtual Cremlingen

A particular challenge in the context of an authentic representation of the visualized drones was the sound design. Since it can be assumed that sound plays an important role in drone acceptance, great importance was placed on the correct simulation of the specific acoustic properties. The source data was generated by test flights and expanded with open source data. It was matched to the corresponding drones and split up in three sections – a start, landing and an idle phase which are triggered according to the status. In addition, influencing factors such as size, speed, flight altitude, rotor diameter, number and type of motors and wind speed are included in the calculation.


Figure 3: Study scenarios A (top) to D (bottom). Drone flight paths (left) and impressions from the 3D scenes (right)

Table 1 gives an overview of the drone types, which were flying in the four scenarios, as well as on their flight altitudes and flight speed. The numbers 1-7 in the table refer to the numbered flight routes illustrated in Figure 3.

| A: Industrial area | B: city center/ main street |
|---|---|
| 1 = delivery drone (50 m, 8 m/s)<br>2 = delivery drone (60 m, 8 m/s)<br>3 = delivery drone (80 m, 8 m/s)<br>4 = delivery drone (100 m, 8 m/s)<br>5 = delivery drone (70 m, 8 m/s)<br>6 = air taxi (150 m, 25 m/s)<br>7 = rescue drone (100 m, 15 m/s)<br>8 = inspection drone (20 m, 8 m/s) | 1 = delivery drone (50 m, 8 m/s)<br>2 = rescue drone (100 m, 16 m/s)<br>3 = filming drone (5-20 m, 8 m/s)<br>4 = filming drone (20-50 m, 8 m/s)<br>5 = air taxi (150 m, 25 m/s) |
| C: residential area | D: park |
| 1 = filming drone (5 m, 8 m/s)<br>2 = filming drone (5-20 m, 8 m/s)<br>3 = rescue drone (100 m, 8 m/s)<br>4 = delivery drone (50 m, 8 m/s)<br>5 = hobby drone (5-20 m, 16 m/s)<br>6 = air taxi (150 m, 25 m/s) | 1 = rescue drone (100 m, 16 m/s)<br>2 = hobby drone (2-3 m, 21 m/s)<br>3 = hobby drone (2-3 m, 21 m/s)<br>4 = hobby drone (3 m, 1 m/s)<br>5 = hobby drone (5-20 m, 16 m/s)<br>6 = air taxi (50-100 m, 8 m/s)<br>7 = delivery drone (50 m, 8 m/s) |

Table 1: drone types flying in the four scenarios with information on flight altitude and flight speed given in brackets

*Sample*

The sample involves participants from different departments of the German Aerospace Center. In total 10 people participated in the study. One person was excluded from the analysis due to sound problems during the simulation. Seven of the remaining nine participants are men and two are women. A majority of seven persons live in cities counting between 100.000 and 500.000 inhabitants. The other two participants are resident in smaller towns. The participants have been recruited via e-mail distribution list. Participants received financial compensation when wanted.

*Procedure*

The study took part in the VRU lab. First, participants were welcomed and briefed about the procedure. They declared their consent to take part in the study. Following they answered a questionnaire related to Simulator Sickness. Participants received a briefing about the OmniDeck and conducted two training scenarios to familiarize with the virtual environment, the hardware and to manage walking on the OmniDeck. At the same time, simple mechanics such as grabbing objects with controllers are trained. The training lasted between 30 to 45 minutes.

Afterwards, they were instructed to imagine it is the year 2030 and that urban traffic has changed. Travelling takes place on ground and in air. They are in Cremlingen, a smaller city with 5000 inhabitants located 15 kilometers away from Braunschweig with 220000 inhabitants. They are supposed to follow a route in different areas of Cremlingen and fulfil some tasks. They are supposed to behave normally as they would do as a pedestrian. Before each of the four scenarios participants saw a map with the route they should take and were instructed about their tasks.

During the experiment, the subject was given several secondary tasks, which varied depending on the sections. The tasks served several purposes at the same time. On the one hand, they should encourage the test person to interact with the environment, thereby increasing the sense of presence. On the other hand, the tasks served to shift the mental capacities of the user. The subject should not focus on the walking itself, but on the interaction in the simulation. The intention was to achieve a more natural gait pattern, increase the feeling of presence and navigate the subject through the environment by strategically placed objects. Tasks were to count cars in a specific color, to search for items, and two times to pick up garbage. These tasks were designed to capture some of the participants attention in order to simulate a more realistic level of occupancy. The presence of drones in the scenarios was masked to participant.

Afterwards participants had a time window of 15 minutes to fulfil their task. Time was limited to avoid simulator sickness. Within each run, participants were instructed to press a trigger every time they felt uncomfortable in the virtual scenery they experience. Furthermore, participants were instructed that they were allowed to share all thoughts and speak with the investigators.

After each run, participants answered questionnaires and run through a semi-structured interview. After the completion of all four scenarios a debriefing was conducted. It consisted of an individual brainstorming session on urban air traffic. Afterwards, an interview was conducted and lastly a questionnaire with demographic items was filled out. At the end of the study participants were explained the goals and research question of acceptance of drone traffic in urban areas. The whole procedure lasted between 2.5 and 4 hours.

*Independent variables*

The scenarios (A to D) served as independent variables. As described above, the scenarios are a combination of both focus area (A = business park, B = city center, C = residential area, D = park) and type of drone use cases. In order to create scenarios with ecological validity, focus area and use cases were combined according to future business cases and not in a systematic experimental design. The chosen use cases per focus area are visualized in Figure 3. The drone use cases can be further detailed by factors that might influence the perceived risks, being selected drone type and visual appearance, flight height and flight behavior.

*Dependent variables*

Individual experience of the scenarios was assessed with eight items that were adapted from the Technology-Acceptance-Model for Video Surveillance questionnaire [12]. The following items have been used:

1. The scenario made me feel nervous.
2. I felt scared in the scenario.
3. To me, the scenario's events appeared to be unforeseeable.
4. In the scenario, I felt as I was being watched.
5. I felt disturbed in the scenario.
6. In the scenario, I felt restricted in my privacy.
7. I felt safe in the scenario.
8. I felt comfortable in the scenario.

After each scenario, participants rated these eight items on a categorial scale (totally disagree, rather disagree, rather agree, totally, agree, not sure). Items seven and eight were inverted. General acceptance of drone was further assessed by a post-study questionnaire.

During the simulation runs, participants marked situations they perceived as disturbing by pressing the trigger of the handheld controllers. Trigger presses were recorded within the logfiles of the simulator. For each scenario time and position of each trigger press per participant was derived, as representing a disturbing situation.

# 5 Results

*Post scenario item comparison*

Figure 4 show the results of the analysis of the eight items related to how participants experienced the four different scenarios. The most positive answers were given for the industrial area. For all items, a majority ranging from seven to nine participants gave answers in the positive spectrum of the scale meaning rather or totally disagreeing to the single statements. For the last two statements, which capture how safe and comfortable participants felt during the scenario, rather and totally disagreements are the positive answer spectra. The second most pleasant scenario is the city center respectively the main street. Five of the items were answered positively by at least six participants, which is more than half of the sample. Aspects rated more negative in this scenario are the unpredictability of event as well as the feeling of being watched and disturbed.

The most negative experienced scenarios are the housing area and the park. For the park scenario the unpredictability of events, the feeling of being watched, disturbed and comfortable were rated in a more negative way by at least half of the participants. For the housing areas, even all items were answered negatively by the majority.

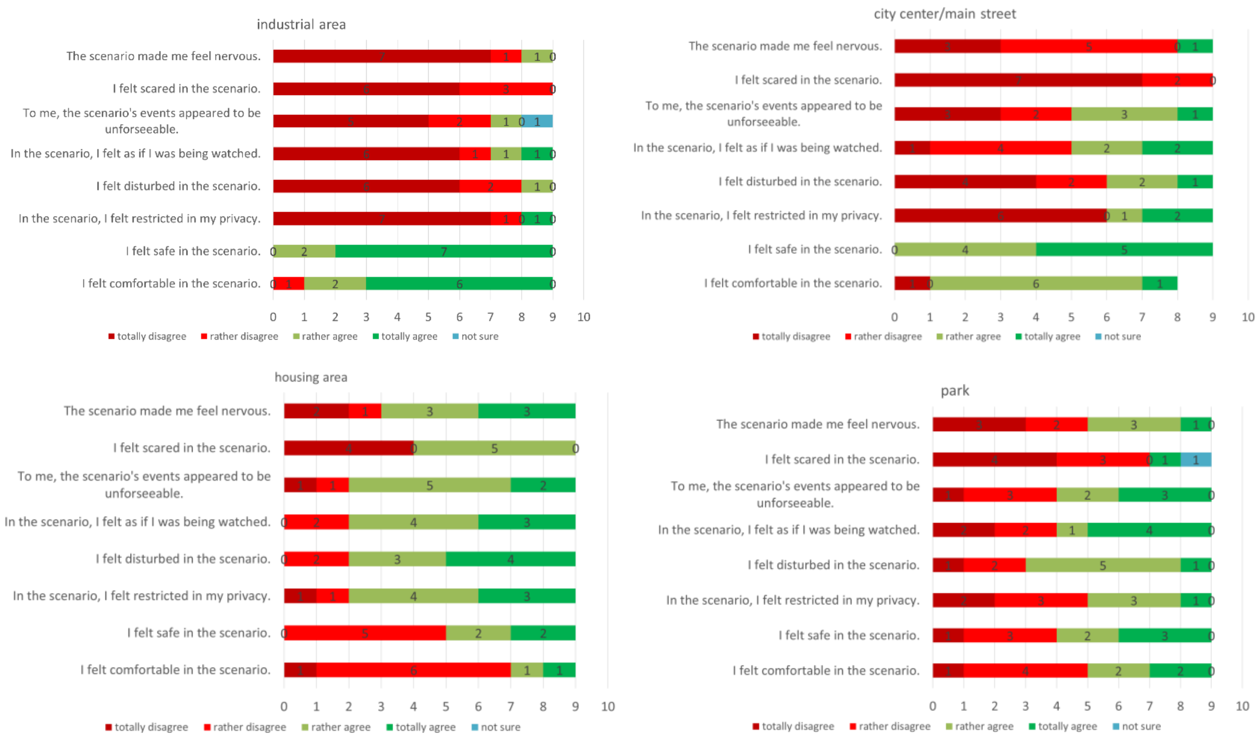


Figure 4: Subjective assessment of different scenarios in total numbers

*Post-scenario questionnaire*

In the final questionnaire answered by the participants after the simulation, approval for drones flying in specific city areas were asked as well as participants concerns related to drones.

Results indicate, that drone flights are mostly tolerated in business and industrial areas, as 8 and nine participants gave positive ratings. In city centers, at least six of the participants would agree to drone flights. According to the ratings, drones would not be acceptable in housing areas and parks (s. Figure 5).

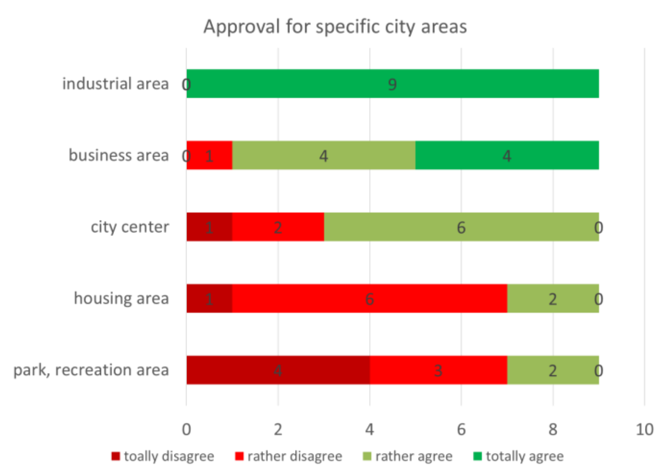


Figure 5: Approval for specific city areas in total numbers

In light of participants' concerns about drones, the findings reveal that each of the presented aspects is a matter of concern to more than half of the sample. The highest concerns are related to noise and that drones might be used for criminal actions (s. Figure 6).

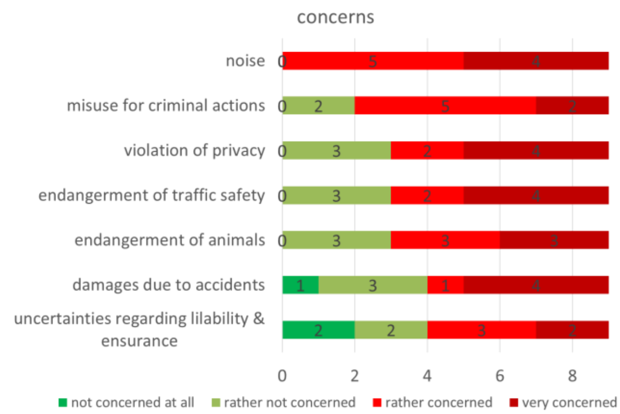


Figure 6: Participants concerns about drones in total numbers

*Detailed analysis of disturbing situations*

Participants could press a trigger in situations where they felt disturbed or uncomfortable. Data from seven participants in four scenarios could be used for this analysis. Overall 111 trigger presses were gathered with a minimum of zero and a maximum of 13 events in one scenario. This result indicates that feeling disturbed is a rather individual evaluation. The average number of trigger presses per scenario was calculated (s. Table 2) Results show that on average in the residential area participants encounter seven uncomfortable situations, compared to 3 and 4 situations in the park and city center, and 2 events in the industrial park.

| **Scenario** | **Mean** | **Sd** |
|---|---|---|
| Industrial park | 1.71 | 1.6 |
| City center | 3.71 | 2.63 |
| Residential area | 7.29 | 5.02 |
| Park | 3.14 | 2.48 |

Table 2: Number of trigger presses per scenario

To further detail the reason for the disturbing situations, a plot of all trigger presses in relation to the position of the drones for the residential area is given in Figure 7. Each black star represents one trigger press, within the plot the triggers of all participants are combined. The colored lines indicate the flight route of drones. What becomes apparent is that the triggers can be clustered into two situations – participants were disturbed be a film drone flying around a house (blue line) and by the hobby / racing drone in a garden (yellow line). In both situations, participants were rather close to the drones and participants did not expect these kind of drone operations within a residential area. This observation is in line with statements participants gave in interviews after experiencing the scenarios. For the residential area eight of them stated, that their attention was primary on drones, especially on the small ones flying around one of the houses and in the garden. As reasons participants expressed their closeness and noisiness. In the plot a concentration of trigger presses can be seen at those points, where the small drones were flying (s. Figure 7).

Figure 7: Plot of trigger presses (black stars) and drones in the residential area

## 6 Discussion & Outlook

This paper described an experimental approach in Virtual Reality to investigate the perception of drones in different urban areas with the leading questions, whether the acceptance towards drone flights differs in the chosen urban settings. The findings reveal, that participant felt mostly disturbed by drones in the residential area and park scenario. One explanation for this observation might be, that the small quadcopters have been very present in this scenario. They had much lower flight altitudes than other drone types and got quite close to people in certain situations. In interviews conducted with the participants after each scenario, some of them expressed that due to the close distance of small drones they were more hearable and participants perceived the noises as surrounding. Furthermore, race and film drones were perceived as annoying, because they conveyed the feeling of being observed. Another explanation for a higher disturbance in these scenarios could be different expectations of people in different urban settings. According to statements of the participants they would not expect so much traffic in parks, as these are recreational zones. In the industrial area most of the participants perceived drones as useful and not disturbing, because a higher general level of surrounding noise is expectable and the application of drones can be useful here. According to the results, the appearance of the scenery and expectations on it probably have an effect on whether drones are perceived as disturbing or not. Therefore, this aspect should be considered also in future studies on social acceptance. The chosen urban scenarios of Cremlingen is representative for many small and medium-sized towns in Germany, but they do not portray megacities. Thus, further research should also pay particular attention on big city scenarios with higher traffic densities.

In this study, the method to use an interactive human-in-the-loop simulation utilizing an advanced pedestrian simulator, has proven valuable to provide participants a realistic and immersive experience of potential future UAM scenarios. To our best knowledge, this was the first approach of a Virtual Reality study, in which participants were not only observers, but could actively move around, experiencing different scenarios and interact within them. With regard to the novelty of this kind of interactive VR scenarios, it was very pleasing to observe that users showed only a very low level of simulation sickness. Hence, no test run had to be interrupted or aborted. Considering that simulation sickness is quite often a major problem in terms of human-in-the-loop (HIL) simulation, this is a great success. Reasons for this are mainly assumed to be the decelerated simulation design (compared to flight or driving simulation) which also translates the subject's movement directly and without delay into the simulation as well as the preliminary and comprehensive introduction of the subject to the system through well thought-out training scenarios.

Moreover, the different tasks given to the participants during training and in the active scenarios simulated daily situations, in which people would not only pay attention on traffic, but rather continue their normal activities instead. This way it could be investigated to what extend people would recognize or be distracted by drones when being focused on other things. In next studies it would be interesting to expand research also on how other road users perceive drones, for example car drivers or cyclists. As they move faster, especially quick and jumpy drone maneuvers might be more surprising and unexpected. Therefore, it should be ensured, that drones do not endanger traffic safety. Furthermore, other road users and traffic noises should be added to the scenarios. In this study the focus was only on the appearance and noise of drones. Future studies should map all traffic and investigate how it affects people.

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