To cite this article: Dickinson, J. , Smith, A. , Drummond , J. , Nadeem , T. , Cherrett , T. , Permana, R. , Waterson , B. , Oakey, A. , 2024 . What do people think about logistics drones? Exploring a possible transport future using virtual reality. Manuscript submitted for publication. Bournemouth University Business School . Bournemouth University.

What do people think about logistics drones? Exploring a possible transport future using virtual reality

Highlights

- Virtual reality enhances people's understanding of logistics drones
- Delivery and environmental benefits of logistics drones need clarification
- Noise of logistics drones is a prominent issue
- Where logistics drones fly matters to people
- Regulation of logistics drone operators is important

Abstract

The introduction of logistics drones into lower airspace has significant implications for the public who have little or no knowledge of the technology. This paper demonstrates the value of using virtual reality (VR) as a place-based approach to explore a largely unknown transport future. The efficacy of the approach is supported by data from a questionnaire survey (n=371) conducted following VR use in five places in the UK. The approach was cost effective and involved participants at a deep level to capture nuanced views. Noise from logistics drones is a prominent issue, where they will fly matters to people and the regulation of operators is also important. The delivery advantages and wider environmental benefits of logistics drones need to be clarified for participants as do actual benefits and impacts of the socially desirable use cases portrayed in trials. We discuss what can be learnt from using this approach, its value in reaching audiences not engaged with transport futures and the opportunities to inform governance and regulatory decisions.

Keywords

- Logistics drones
- Virtual reality
- Noise
- Regulation
- Public involvement

1. Introduction

Advanced Air Mobility (AAM) technologies, such as logistics drones, envisage a significant shift from traditional aviation and ground-based transportation of goods and people. While current research is examining regulatory frameworks (Regulatory Horizons Council, 2021), there is little clarity on how new classes of air vehicles will operate, including use scenarios, the volume of traffic likely to be generated, operating parameters and locations. This makes it difficult to engage the public and explore stakeholder views (Smith et al., 2022a) and must be addressed so that people with no direct experience or knowledge of AAM technologies can shape future scenarios that will be relevant to their lives (Camilleri et al., 2022). A fundamental research challenge is how to involve the public with a transport future that is not yet present in their lives to facilitate involvement in informed debate of what it might mean to live with AAM technologies.

Logistics drones feature in the transport ambitions of many countries, including the UK (UK Research and Innovation, 2021). These technologies are high on some government agendas and funding priorities due to purported economic benefits with PWC (2022) estimating a net cost saving for the UK from the use of drones in transport and logistics of £4.2 billion by 2030, though such claims are unproven (Smith & Powles, 2022). There are also perceived opportunities to address pressing ground transportation problems such as congestion, breaches of local air quality standards and global GHG emissions, though this is dependent on many factors (International Transport Forum, 2021). This presents an optimistic agenda for the adoption of logistics drones (Smith & Powles, 2022) despite many of the operational parameters and suitable use cases being currently undetermined. Whilst these technologies have seen significant use in several developing countries (for example, Zipline in Rwanda (Nisingizwe et al., 2022)), where there may be challenging geographies, less comprehensive land transportation infrastructure, and relatively few restrictions on integrating drones into existing airspace structures, the pace of adoption in developed countries has been much slower due largely to greater regulatory requirements. In developed countries, trials are ongoing and, while examples of last-mile drone delivery services are emerging, for example the delivery of retail items in a suburb of Dublin, Ireland (Manna, 2024), for widespread adoption, governance and regulatory issues still need to be resolved. To this end, it is vital to involve stakeholders, including the public (International Transport Forum, 2021; ERSG, 2013).

While drones are not a new technology, the UK population are most familiar with small drones used for leisure flying or photography, though there is growing awareness of the scope to use drones in logistics (Marshall et al., 2022). People in the UK are unlikely to have been exposed to logistics drones and their views of drones will be largely socially derived, based on more direct experiences of smaller drones, and portrayals in the media which has focused on delivery services with social value (Smith et al., 2022b). This paper presents a place-based research approach utilising virtual reality (VR) which brings logistics drones to a general audience in everyday spaces. VR offers a low-cost solution to present more realistic logistics drone scenarios without the need for live demonstrations, which are challenging due to airspace regulations. This extends work visually representing logistics drones (Thomas and Granberg, 2023) by illustrating drone movement and sound. The aim of using VR was to help people reflect on this future transport scenario.

A growing body of research has sought to capture the general public's view of drones and analysis shows four significant problems with these studies. First, they conflate different civil drone uses and it can be unclear exactly what people are responding to given the variety of drone types, uses, operating parameters and locations considered (Smith et al., 2022a). Given that many drones are used in discrete settings (for example, monitoring of nature conservation areas) and for limited one-off uses (search and rescue, surveying or photography), most drone use would not impinge much, if at all, on the public. However, if drones are to play a significant role in logistics operations, they will need to operate in the towns, cities and countryside where people reside, and therefore closer attention needs to be paid to public views (Smith & Powles, 2022).

A second problem is the high priority placed on work to understand acceptance (International Transport Forum, 2021; ERSG, 2013) which risks assuming an inevitability of implementation (Smith et al. 2022b; Stilgoe & Cohen, 2021). Hopkins and Schwanen (2018) suggest that in the absence of a defined system of provision it is not clear what policy makers are asking the public to accept, with the danger that engagement represents a ‘rubber stamping’ exercise.

A third problem is the difficulty for people to imagine and discuss a transport future that does not yet exist. Trials go some way to address this, but these are costly, limited by permissions to use airspace (particularly where beyond-visual-line-of-sight (BVLOS) operations are involved), take place in discrete locations, often in specified flight corridors, are of a limited duration, undertake few flights, and lack visibility to the public beyond the vicinity of a trial. Trials focus on resolving the technical issues. They are exploratory and therefore the operating parameters on frequency of flights, altitude, flight paths and many other details are still being explored. Trials are therefore unlikely to reflect actual service delivery. While there is much to be learnt from trials, they are led by the ambitions of the operators and tend to represent logistics drones in an advantageous way, for example, as a tool for the public good (see for example, The Guardian, 2022) or one that will save time and energy (Smith & Powles, 2022), when the comparative advantages of using drones are far from clear (Grote et al., 2024; Oakey et al., 2022).

The fourth problem is involving a general audience in a topic which is not salient for many given that logistics drones are not high on the public-facing political agenda, nor present at this point in everyday life. When people are asked about new technologies, they are found to not understand the use cases or environment into which these use cases will be deployed (Stilgoe & Cohen, 2021). Studies on climate change have shown that it is hard for people to relate to general information and materials need to be contextualised at a neighbourhood scale in personal contexts (Kopsel et al., 2017). Smith et al. (2022a) further note that public views on drones are easily altered. Novel engagement tools are needed to reach a disengaged audience (Smith et al., 2022a) and involve people in debate about the reality of operating parameters, including what logistics drones might look and sound like, where they might fly, when they might fly, at what altitude, how frequently and for what purpose.

A contextualised approach will help address these critiques. The purpose of this paper is to demonstrate the value of VR to explore an unknown transport future involving logistics drones. Our approach is designed to be transferrable to other settings. The efficacy of the approach is supported by empirical data from a questionnaire survey conducted immediately following VR use.

2. Literature and theory

2.1 Beyond public acceptance

A growing body of research has explored public reactions to the civil usage of drones. This has focused on perceptions, attitudes, knowledge and concerns, with most studies framed around understanding public acceptance (see for example, Aydin, 2019). This reflects a desire by those developing and promoting drone technologies to understand the resistance to drone technology which is positioned as a public acceptance challenge (see, for example, Eißfeldt et al., 2020). This perspective strives to shift people to accept and use new technologies. The latter is a deficit model (Joffe, 2003; Sherry-Brennan et al., 2010; Stilgoe & Cohen, 2021) which questions the ability of the public to give a considered judgement.

To overcome this, Batel and Devine-White (2015, p316) stress the need for research contextualised to 'space and place' in their work on new energy technologies where "people may agree, in general, with something which is being fostered by laws or has a normative character, and disagree with that same object when it is materialised in proximal/everyday contexts". Furthermore, Batel and Devine-White (2015) highlight how questions about new technologies can bring issues to the fore that are not necessarily found unless explicitly asked, reflecting concern with the framing of questions (Sherry-Brennan et al., 2010). This is evident in research addressing the public's acceptance of drones where Smith et al. (2022a) demonstrate how questions have prompted responses that were otherwise not forthcoming. Smith et al. (2022a p9) argue future logistics should move beyond a model of public acceptance of drones to one that "enables the public to truly engage in drone use scenarios to inform decisions on provision". This requires new mechanisms that build understanding of logistics drones in environments where they may be deployed that provide space for reflection and responses that are not led by acceptance agendas. Our approach is grounded in involving participants to realise the true benefits and challenges of logistics drone technologies.

2.2 Envisaging transport futures using virtual reality

Several studies have used VR in the transport field, finding it valuable as a research tool to inform decisions/policies before making and implementing them in real life (Farooq et al., 2018; Erath et al., 2016). VR overcomes the problem of asking about a hypothetical scenario and is particularly useful for future forms of mobility that do not exist yet in the real-world (Farooq et al., 2018). In work on connected autonomous vehicles, Farooq et al. (2018) noted how participants' understanding of the technology and its capabilities was likely to be limited and that this impacted on the views expressed. VR goes some way to addressing this problem by providing a visual and audio representation of the vehicles.

Using VR in this way aligns with presence theory which originates in work on 'social presence' with respect to the level of human contact required for communication to be successful. The strongest presence is achieved through face-to-face encounters, then audio/visual connections (for example, phone or video link) and the weakest via written communication. 'Presence' gives the feeling of being there or losing oneself and includes physical, spatial, or environmental presence (Fox et al., 2009), which is the focus with logistics drones in this study. Presence helps people to feel situated in the environment and this prompts engagement (Bialkova et al., 2018). Rather than transporting people to another environment, which is typical in VR experiences, the VR described here brings logistics drones to the place where participants are present.

VR adds realism and immersion in the virtual space enhances engagement with tasks. It is considered a new avenue for citizen engagement and communication and can expose people to a range of multisensory phenomena that would be difficult to replicate in reality (Fox et al., 2009). VR is multisensory, combining audio and visual representation which has been found to be highly effective when exploring transport systems (Torija et al., 2020). Our logistics drone VR therefore focuses on the whole environment when the drone is in flight. It is a situated experience in which noise and visual impacts will vary by context.

VR is underutilised in the social sciences (Fox et al., 2009). In the transport field studies are emerging that explore responses to transport infrastructure (see for example, Mertens et al., 2020, Bialkova et al., 2018 and Bogacz et al., 2021 who used VR to address cycling, and Agudelo-Velez et al. (2021) on travel routes and security). In these studies, VR circumnavigates the risk of conducting experiments in-situ and overcomes the problems associated with revealed preference (capturing past experiences) and stated preference (hypothetical scenarios that lack realism) (Farooq et al., 2018). Research to date has largely focused on the development of VR, the methodology for its use and comparisons with real experiments rather than empirical research.

3. Methodology

To the best of our knowledge, this is the first study to engage participants with a realistic audio-visual experience of logistics drones which presents them in proximal everyday contexts using VR. Earlier studies indicate that people reference smaller hobby drones in their representations of logistics drones given their more widespread use and therefore need exposure to larger logistics drones and their flight mechanics (Smith et al., 2022a). An inductive and exploratory research approach sought to capture the range of views held by participants as well as potential contradictions and dilemmas as participants would be unlikely to hold a singular view of logistics drones at this stage. Data were captured using a post VR questionnaire using open questions and checklists.

The VR experience was designed so it could be transposed onto any place location. The design evolved through a series of pilots. The final VR included two types of logistics drones, a fixed-wing hybrid drone and a multi-rotor drone (Figure 1), both capable of vertical take-off and landing to provide different examples of common logistics drones (see Darvishpoor et al., 2020 for a taxonomy of drones and for logistics drone use cases). Interested readers can find the technical details of the VR development in Appendix A.

The drones fly across at three heights (30m/100ft (multi-rotor), 76m/250ft (fixed-wing) and 122m/400ft (multi-rotor)) (Figure 2) at a speed of 40 mph/18 m/s. The VR visualised six drone flights, one after another, in around 3 minutes (including introductory text) to give participants a time compact experience of the two drones flying at varied altitudes and typical cruising speed. This does not reflect anticipated frequency of flights and participants were made aware of this in the written participant information, by the researchers just before VR use and through introductory text in the VR headset as follows:

> 'You will see delivery drones fly past 6 times at varied altitudes
> There are two types of drones illustrated
> The flight frequency is for illustration only and does not reflect foreseeable real-world use'

The survey tool also highlighted that there could be large variations in flight frequencies which helped participants understand that, were logistics drones to be introduced in the UK, the flight frequency is yet to be determined.

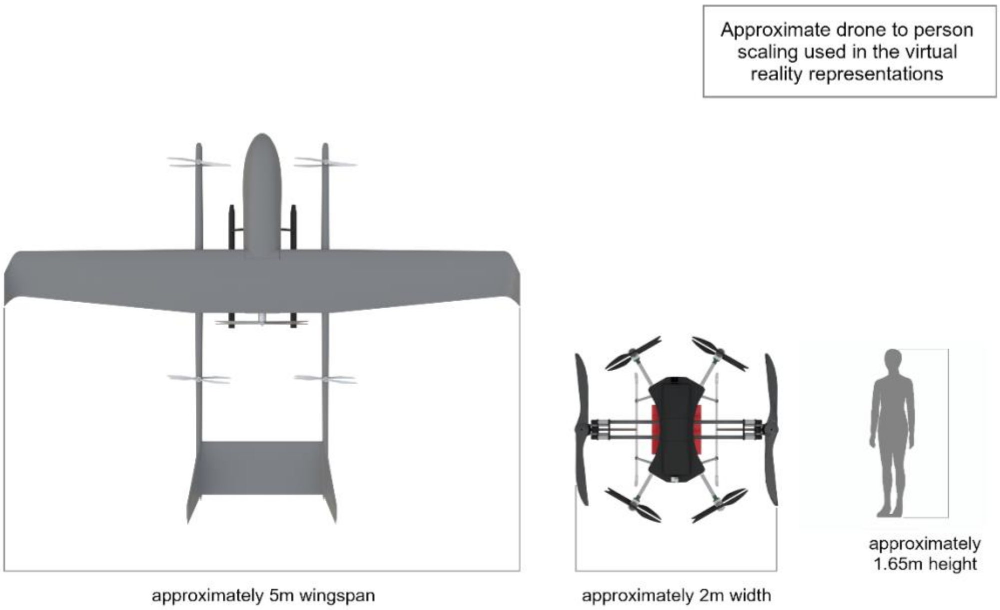

Figure 1. The fixed-wing hybrid and multi-rotor drone designs compared to average human height (Roser et al., 2013)

		
Multi-rotor at 30m	Multi-rotor at 122m	Fixed-wing at 76m

Figure 2. The two types of logistics drones flying over an example site at 30m, 76m and 122m

The study was cross-sectional with data collected during summer 2022 and 2023. A convenience sample was deployed in three town/city centres (Boscombe, Bournemouth and Southampton), a rural site (Lepe Country Park) and a suburban site (Southbourne) in Southern England (see Figure 3) reflecting a range of socio-economic contexts accessible to the research team. The 10 data collection days included weekdays, school term time, school holidays and weekends. Participants were approached by team members as needs dictated to avoid queues for VR headset use. Approaches were made on a next-to-pass basis and to potential participants in adjacent public seating areas. Some participants read project posters and asked to take part. The response rate was around 1 in 12 but varied depending on place and conditions (for example, poor during a period of rain). Participant composition was periodically reviewed with the aim of involving a range of adult (18+) participants to reflect, as far as possible, UK age and gender demographics. This led to some targeting of older participants. Participants received at £5 shopping voucher in recompense for the time taken.

Boscombe (town centre)

Bournemouth (town centre)

Southampton (city centre)

Lepe Country Park (rural)

Southbourne (suburban)

Figure 3. The five study settings showing the fixed-wing hybrid drone

The questionnaire was self-completed immediately after the VR experience and designed to enable participants to reflect on drones in logistics. Participants were offered the choice of completion on a tablet computer or paper. Studies examining public views of drones have commonly employed attitude and acceptance scales which can prompt responses by raising issues that respondents have not previously thought about and results can be led by the researchers' a priori conceptualisations (Smith et al., 2022a) perpetuating a particular view of logistics drones. This study sought to avoid leading the participants and therefore utilized open questions to freely elicit views without prior categorisation. This approach captures the saliency of issues for participants (Bryman, 2001). A checklist was also used to help participants reflect on where it would be appropriate for logistics drones to fly. This was based on analysis of qualitative data captured during the VR pilot process and the researchers' reflections on issues being raised in the wider project around drone routes. The checklists asked respondents to identify connections between drone flight frequencies and various settings. This included a section specific to medical logistics in the three town/city centres. Having drawn conclusive findings on this, the medical logistics question was dropped in the rural and suburban study sites to reduce the participant load and an additional 'over countryside' category added to the checklist. Descriptive data about participants were compiled using closed questions including knowledge and experience of drones (based on questions used by The Department for Transport, 2021) and some basic socio-economic and demographic data. These questions were used to check the sample was representative and in analysing the salience of views to different groups. The questionnaire is attached as Appendix B.

The VR and the questionnaire were developed and tested at four events (two public engagement events and two test events). This led to refinements to the VR and finalised the questionnaire format. A final pilot involving 95 participants was undertaken over two days in July 2022. No changes were made to the VR and the questionnaire was only altered to capture data on ethnicity following the pilot, so these 95 responses (part of the Boscombe sample) were combined with the main study.

The data collection took place between 09:00 and 16:30 in busy places. A 3m x 3m gazebo was used to screen out UV interference with the VR headsets. This also provided a secure enclosed space for the participants and researchers. Posters on the side of the gazebo invited participants to take part and highlighted the £5 incentive. Banners along the top of the gazebo made clear the activity was research linked to universities. Two Oculus Quest 2 headsets were used. The process was managed by a minimum of four research assistants working as a team with one recruiting, two managing the VR headsets and one managing the ethical, health and safety protocols and questionnaire completion.

While the approach to data collection worked well, there were challenges. Given the UK climate, weather is unpredictable and data collection was not feasible in high winds due to stability of the gazebo and wet conditions reduced foot fall. This meant reserve days needed to be planned. A small number of participants were unable to use the VR (3%) due to allergies or concerns about visual disturbance. These participants completed the questionnaire, so as not to exclude anyone, but the data is not reported here as these participants did not have the VR experience. Other approaches are needed for these participants.

The data analysis strategy was founded on inductive reasoning. The open questions were reviewed thematically and then content analysed to identify key categories (Weber, 1990) based on an emergent coding system. Three researchers reviewed the answers, compared notes and developed a category list. This category list was then applied by two researchers to the data, the coding compared, disagreements discussed and adjudicated by the third researcher. Categories were then entered into SPSS as binary data (presence/absence). The checklist generated ordinal data that were not normal therefore non-parametric tests were used.

4. Results and discussion

Overall, a representative sample of men and women was achieved as was a good spread of ages and ethnic groups (Table 1). The 18-34 age group was overrepresented, which is unusual in consultations on transport (Bertram, 2023). It was positive to see the approach reached out to this group which, according to criteria proposed by Fanning and Bridge (2023), is likely due to the £5 incentive, use of interactive and engaging methods, using accessible locations at times when young people are about, topic and peer facilitators (a relatively young research team). Asian and Black participants were notably absent from the rural and suburban study sites. Most participants had heard of drones, though knowledge was limited (Table 2). The majority had never used a drone (Table 2) though this percentage was lower compared to Marshall et al. (2022) who found 85% have never used a drone and may reflect some participant self-selection bias due to interest. Overall, the VR provided an immersive and engaging experience that was able to reach a relatively large and diverse audience that would not normally take part in transport consultations (n=371) over 10 days with limited resources.

Table 1. Sample composition

	Boscombe[1]	**Bournemouth**	**Southampton**	**Lepe Country Park**	**Southbourne**	**Total**	**2021 Census England**
	(n=95) %	(n=71) %	(n=75) &	(n=97) %	(n=33) %	(n=371) %	%
Gender							
Male	48	52	55	49	30	49	49
Female	52	48	45	51	70	51	51
Age							
18-24	12	26	26	8	13	17	11
25-34	26	20	34	10	7	21	17
35-44	17	17	14	29	10	19	16
45-54	14	17	7	18	13	14	17
55-64	17	14	11	16	27	16	16
65-74	7	3	8	14	17	9	12
75-84	3	3	1	4	10	4	8
85+	4	0	0	1	3	2	3
Ethnic group[1]							
White		66	51	97	89	76	82

Asian, Asian British or Asian Welsh	9	12	0	0	5	9
Black, Black British, Black Welsh, Caribbean or African	2	3	0	0	1	4
Mixed or Multiple ethnic groups	2	7	2	4	4	3
Other ethnic group	4	8	1	7	5	2

[1]Data not available for Boscombe on ethnic group

Table 2. Knowledge and experience of drones

How much, if anything would you say you know about drones?	%
Hadn't heard of them before now	3
Hardly anything but I have heard of them	13
A little	45
A fair amount	28
A lot	9
Don't know	2
Have you every personally used a drone?	
Yes, used one personally	24
Yes, used one for commercial or work-related reasons	4
No	72

4.1 Initial comments on logistics drones and their regulation

Following the VR experience, the participants were first asked an open-ended question: "What are your initial comments on the use of drones for making deliveries?" (Table 3). Responses were nuanced with participants articulating a range of views rather than a simplistic statement of acceptance or rejection. For example, "a good idea and will increase efficiency of delivery, noise could be an issue in residential zones but in daytime on high street a good idea". Here the positive view is moderated by noise concerns. This reflects work on renewable energy technologies where there can be high support but opposition in everyday proximal contexts (Batel & Devine-White, 2015). Later in the questionnaire, participants were asked "What feedback would you give to those responsible for developing regulation?". The answers were thoughtful and often encompassed multiple intersecting issues (Table 4). The initial comments and feedback on regulation included similar points and these are therefore discussed together.

Table 3. Initial post VR comments on the use of drones for making deliveries

Topic	Summary	N[1]	%
Noise negative	Concerns, questions and thoughts about noise impacts	119	32
Delivery advantages	Speed and time saving; use case to islands; value for people less able to leave home; value for urgent deliveries; trustworthy delivery	104	28
Safety and accidents	Airspace conflict, drone malfunction, crashes, dangerous, items being dropped	53	14
Environmental benefits	Reduced energy use and/or carbon footprint, more efficient, broad comments on less pollution and environmental benefits	42	11
Questions or concerns about technical capabilities	Who controls and trust concerns about operators, weather impacts, weight limits, better ways for delivery	41	11
Annoyance NOT noise focused	Annoying in general, visual intrusion, distraction, disturbance	39	11
Road traffic reduction	Assumed reduction in road traffic or congestion	31	8
Privacy	Concerns about camera use and surveillance, including Government surveillance, and what happens to data (video data or other data held by operators)	28	8
Drone frequency	The number of drones needed, time of day and routes	28	8
Job loss	Loss of work for delivery drivers	25	7
Environmental concerns	Questions/comments about efficiency, impact on wildlife/animals, bad for the environment generally	22	6
Security	Concerns about malicious activity (e.g., theft, use by criminals), interference with the drone	22	6
Medical use case	References to medical use scenarios	21	6
Altitude	Impacts related to altitude	20	5
Positive/neutral comments on noise	Noise compared to cars (positive or neutral), generally noise neutral, will be okay if noise is addressed and need for more clarity on noise	12	3

[1] items with 10 or more mentions included in the table

Table 4. Feedback to those responsible for developing regulation

Topic	Summary	N[1]	%
Noise impact	Mentions noise, sound, or the need for delivery drones to be quiet, suggestions of measures to reduce potential noise, mentions that noise may be or is a problem	106	29
Operating parameters	Where the drones would fly/routes, appropriate altitudes, frequency, speed, conditions (e.g. weather)	88	24
More research and consultation	Comments indicating a desire for more trials, research, consultation etc. e.g., national surveys	43	12
Safety	Address general safety concerns, specific aspects such as mid-air collisions, safety of rotors	41	11
Regulation of operators	Mentions rules, regulation, or laws, responsible and safe practice, safeguards, training, licencing/registration, monitoring, enforcement	35	9
Evaluate impact on the environment	The need to evaluate aspects of environmental impacts and benefits (e.g., energy saving potential), also includes comments on environmental impact of drone equipment (e.g., batteries)	26	7
Privacy	Mentions privacy including managing data and photography, and thinking about privacy in terms of where delivery drones fly	24	7
Security	Relates to managing/preventing the threat of criminal activity/improper use.	21	6
Impact on animals and wildlife	Issues around impacts on animals (including farm animals) and wildlife (including birds)	15	4
Medical or non-commercial priority	Priority given to medical or other non-commercial operations	10	3
Impact on jobs	Concerns about loss of jobs for drivers/bike couriers	10	3

[1] items with 10 or more mentions included in the table

Responses focused on noise were significant and more prominent than privacy, safety and security concerns which have featured strongly in other studies (see for example, Department for Transport, 2018, European Union Aviation Safety Agency, 2021). This is likely to be a response to the audio experience as Eißfeldt et al. (2020) found noise concerns increase when people have experienced the sound and noise is considered a risk factor for expansion of drone uses in urban areas (Torija et al., 2020). Negative comments focused on noise impacts in particular settings (residential), times of day (for example, at night), at lower altitudes, and relative to cars. Many simply described the drones as ‘noisy’, which reflects anecdotal reports of noise complaints related to trials (Stonor, 2022), and some felt the noise impact was unclear. Research suggests there may be health impacts from drone noise, but further research is needed to establish the parameters (Schäffer et al., 2021). Comments on noise were largely negative, but there were some who found the noise less invasive than they expected, for example, “my initial thought was that they would be too loud, but they are actually not that loud” and “quieter than cars and vans” (categorised as ‘positive/neutral comments on noise’). Participants also commented on other ‘annoyance’ factors related to drones (visual, general distraction and disturbance) reflecting concerns about frequency, for example, “too invasive for general deliveries”.

Hearing logistics drones prompted much reflection on regulating noise impact. It was suggested that noise levels should be addressed by the technology developers. Further research with a carefully calibrated and controlled audio experience is required to ascertain true noise impact in varied settings representing different sized drones using a variety of propulsion systems which could build on simulation work by Tan et al. (2023) who note also the impact of drone speeds and payloads. Operating parameters was also a common consideration for regulation and encompassed flight paths, hours of operation, frequency and altitude, often with reference to noise concerns and general intrusion. The product type transported was important for operating parameters and noise considerations, with comments suggesting a need for fewer limitations on flights associated with both urgent and non-urgent medical deliveries. This reflects research in Canada on the use of drones to transport defibrillators where it was rare for a negative reaction (Sedig et al., 2020), though in the present study some participants were opposed to logistics drones for any use case.

Safety was a prominent theme which aligns with earlier studies (see for example, European Union Aviation Safety Agency, 2021) and participants also raised this in relation to regulation of operators focused on a variety of concerns related to hazards for people and animals arising from failure, network signal issues and collisions. Security concerns, including that the drones could be used for illicit purposes, and job loss were also mentioned.

Compared to previous studies (for example, European Union Aviation Safety Agency, 2021; Marshall et al., 2022), privacy related to camera use and the associated data security was much less prominent and may reflect seeing the logistics drones pass quickly in the VR and no hovering close to people. Bajde et al. (2017) found that drones flying past quickly presented less of a privacy concern. The public are more familiar with hobby drones which hover and record images for personal use and hobby drones will have influenced views of privacy infringements in earlier studies where drone uses are often confounded (Smith et al., 2022a). Nevertheless, privacy remains an operator regulation issue for some, however, the VR has enhanced people’s understanding of logistics drones and how they differ to other drones.

Many participants suggested delivery benefits related to use cases, including medical logistics which was in the news at the time of the field work (The Guardian, 2022), and the value for people unable to leave home, speed of delivery and efficiency. Participants also assumed drones would reduce congestion (for example, “it will reduce congestion and lower fuel consumption”), however, drone payloads are generally small, for instance the V50 drone has a payload of up to 15kg (Skylift

2023), so the impact is negligible. Drone services are unlikely to substitute road-based logistics on a significant scale (Oakey et al. 2022) and in some circumstances may represent additional traffic movements (Smith & Powles, 2022). Some identified the value in areas with challenging geographies (for example, use case to islands which was in the national media at that time (The Guardian, 2022)) and for urgent items. Several potential environmental benefits were also mentioned related to energy use, carbon footprint and general pollution.

Meanwhile other participants raised environmental concerns specific to the technology. These have not featured prominently in earlier work exploring public views but are apparent in the European Union Aviation Safety Agency (2021) study which prompted respondents to rank a list of seven concerns "most concerning" to "least concerning". In the present study concerns were unprompted. Participants raised issues about battery disposal, questioned the energy efficiency and carbon neutrality of the drones, wanted regulators to be sure that logistics drones would be a more eco-efficient option and reflected on the impact on wildlife and/or animals, for example, disturbing dogs and wild birds. If there were no environmental benefits, then some participants questioned the point of logistics drones. This is important given the phase-out date for new petrol and diesel vans is on the horizon in the UK (GOV.UK, 2021), therefore the energy use and emissions performance of logistics drones needs to be an improvement on electric vans. Studies indicate some environmental gains can be made, but at significantly higher cost as electric vans offer economics of scale and can service sites where drones cannot land (Oakey, 2023), it is therefore vital that an honest appraisal of the environmental benefits is undertaken echoing the findings of Camilleri et al. (2022).

Participants also used open questions to reflect on areas where they felt details needed clarification. These covered flight paths (frequency, locations, altitudes, airspace conflict) and comments on whether there were better ways for deliveries related to efficiency, weight limits and weather impacts. This shows that while some participants make assumptions, others recognise that there are issues that need to be resolved. The VR therefore prompted in-depth reflection with participants thinking about benefits and impacts, settings, time of day, altitude, frequency and products that might be delivered. Importantly for researchers, participants were keen for more research and consultation so people could better understand the issues. One participant noted that regulators should consider people's lack of knowledge, recognising that there are misplaced assumptions about drones that might skew views both positively and negatively. The VR approach would be valuable here as it can reach larger audiences than trials to help build better understanding and prompt deeper reflection.

Cluster analysis was applied to the categories derived from the "initial comments" question (Table 3) in order explore whether there were groups of participants with shared views. A within group linkage method and pattern difference measure for binary data was used which is a dissimilarity measure and produces tight clusters. Two categories from table 3 were excluded: 'positive/neutral comments on noise' as fewer than 5% mentioned this; and 'job loss' as this grouped across several clusters making interpretation challenging. A five-cluster solution was identified based on conceptual sense and percentage changes in heterogeneity of the agglomeration coefficient in SPSS (Hair, 2014) (Table 5):

- Cluster 1: concerned about noise and intrusion
- Cluster 2: anticipate delivery benefits with some concerns
- Cluster 3: assume environmental gains and delivery benefits with few concerns
- Cluster 4: concerned about technology capabilities, accidents and misuse
- Cluster 5: concerned about multiple issues

These results indicated some polarisation of views. Clusters 2 and 3 focused on benefits, while Clusters 1, 4 and 5 focused on concerns. The clusters did not vary by study site and there were no discernible patterns across socio-demographic variables.

Table 5. Clusters compared to categories of initial comments on the use of drones for making deliveries

	Cluster					
	1	2	3	4	5	All
	n=96	n=101	n=41	n=67	n=66	n=371
Initial comments	% mentions					
Concerns						
Noise negative	60	21	12	2	52	32
Safety and accidents	3	10	0	22	38	14
Questions or concerns about technical capabilities	9	4	2	33	8	11
Annoyance NOT noise focused	28	7	0	8	0	11
Privacy	3	7	5	3	21	8
Drone frequency	23	3	2	3	0	8
Environmental concerns	3	5	0	3	18	6
Security	1	1	0	24	6	6
Altitude	14	1	2	2	6	5
Benefits						
Delivery advantages	5	72	56	2	2	28
Environmental benefits	6	1	81	2	2	11
Road traffic reduction	2	3	39	10	5	8
Medical use case	2	19	0	0	0	6

4.2 Where should drones fly?

The questionnaire captured participant views on where they thought it would be appropriate for logistics drones to fly using a checklist (Tables 6 and 7). The data show a wide spread of views on flight frequencies over all settings. Unsurprisingly, the data show participants were most circumspect about logistics drone flights over housing, their own homes, countryside and urban parks, that is places people live and take part in leisure. Participants were most supportive of flights in industrial settings. This aligns with the findings of Tan et al. (2021) in Singapore, but contrasts with Thomas and Granberg's (2023) work in Europe. Both Tan et al. (2021) and Thomas and Granberg (2023) use static images of multiple drone applications without place specific relevance for participants, while the VR representation helped participants specifically contextualise logistics drones to their physical environment at the time of the study. Data collected at the three urban study sites included a question on medical delivery drones finding some participants considering drones inappropriate even in a medical use scenario (Table 6). A related samples Wilcoxon signed rank test indicated significant differences between medical and general deliveries in each respective over flight setting except for the industrial setting (Table 8) revealing the social desirability of supporting medical purposes. This again contrasts with Thomas and Granberg's (2023) who found no differences between medical and non-medical uses. The VR itself was agnostic about the items being delivered in contrast to trials which have focused on medical logistics in the UK. These findings demonstrate how trials based around medical logistics have scope to garner public support and that this might be a disingenuous way to present logistics drones, especially since viability and cost effectiveness of use cases for medical logistics are not yet established (Grote et al., 2024; Oakey et al., 2022; Oakey & Smith, 2024).

In the rural and suburban samples 'over countryside' was introduced as a setting and therefore results on flight frequencies are reported separately. Responses from the rural and suburban samples were more negative about flight frequencies across all settings (Table 7). A Friedman's ANOVA indicates significant differences in responses between settings. Follow up analysis using a stepwise step-down procedure identified 4 subsets for the urban study sites, with 'over my home' and 'over an area of housing' clustering together as a homogeneous subset (see table 9). For the rural and suburban study sites (including 'over countryside') 3 subsets were identified (Table 9).

Table 6. Which settings do you think it would be appropriate for delivery drones to fly over? (urban settings: Boscombe, Bournemouth, Southampton)

	No drones flying over (%)	No more than four drone flights a day (%)	A drone flying over every hour (%)	A drone flying over every 30 minutes (%)	A drone flying over every 15 minutes (%)	*M*[a]	*SD*	
General logistics								
Over my home	34	31	17	5	13	2.32	1.344	Few to more flights
Over an area of housing	29	31	20	8	11	2.42	1.296	
Over an urban park	29	19	18	13	21	2.79	1.507	
Over a town or city centre	15	13	20	20	33	3.43	1.430	
Over an industrial area	13	6	10	11	59	3.97	1.461	
Medical logistics drones								
Over my home	18	22	18	13	28	3.10	1.487	Few to more flights
Over an area of housing	16	21	21	14	29	3.19	1.442	
Over an urban park	17	14	16	19	35	3.40	1.492	
Over a town or city centre	9	11	16	19	45	3.79	1.359	
Over an industrial area	8	10	11	11	60	4.04	1.360	

[a]Note: No drones flying over =1 to a drone flying over every 15 minutes =5

Table 7. Which settings do you think it would be appropriate for delivery drones to fly over? (rural and suburban settings: Lepe Country Park and Southbourne)

	No drones flying over (%)	No more than four drone flights a day (%)	A drone flying over every hour (%)	A drone flying over every 30 minutes (%)	A drone flying over every 15 minutes (%)	*M*[a]	*SD*	
General logistics								
Over my home	43	32	17	8	1	1.92	1.078	Few to more flights
Over an area of housing	38	37	17	8	1	1.97	.964	
Over countryside	44	26	20	8	2	1.98	1.078	
Over an urban park	34	30	24	6	6	2.21	1.164	
Over a town or city centre	23	25	22	19	11	2.68	1.306	
Over an industrial area	11	14	28	16	31	3.43	1.345	

[a]Note: No drones flying over =1 to a drone flying over every 15 minutes =5

Table 8. Wilcoxon test results comparing general logistics and medical logistics in urban study locations

	General Mdn[a]	Medical Mdn[a]	T	*p*	*r*	Effect
Over my home	2	3	6330.5	< .001	.57	Large change
Over an area of housing	2	3	7007	< .001	.55	Large change
Over an urban park	3	4	5060.5	< .001	.49	Medium change
Over a town or city centre	4	4	3738	< .001	.32	Medium change
Over an industrial area	5	5	917	.195	.08	No effect

[a]Note: No drones flying over =1 to a drone flying over every 15 minutes =5

Table 9. Friedman's ANOVA Homogeneous Subsets

Urban study sites		Subset			
($X^2(4) = 355.833$, $p < .001$)		1	2	3	4
Sample[a]	Over my home	2.220			
	Over an area of housing	2.337			
	Over an urban park		2.805		
	Over a town or city centre			3.576	
	Over an industrial area				4.061
Test Statistic		1.530	[b]	[b]	[b]
Sig. (2-sided test)		.216			
Adjusted Sig. (2-sided test)		.456			

Rural and suburban study sites		Subset		
($X^2(5) = 241.410$, $p < .001$)		1	2	3
Sample[a]	Over my home	2.730		
	Over an area of housing	2.840		
	Over countryside	2.891		
	Over an urban park	3.293		
	Over a town or city centre		4.094	
	Over an industrial area			5.152
Test Statistic		7.610	[b]	[b]
Sig. (2-sided test)		.055		
Adjusted Sig. (2-sided test)		.081		

[a.] Each cell shows the sample average rank.
[b.] Unable to compute because the subset contains only one sample.

Given the more negative response to flight frequencies from the rural and suburban study sites, a Kruskal-Wallis test compared responses across all five study sites. Flight frequencies were significantly affected by study site for all settings ($p > .05$) except 'over my home'. However, pairwise comparisons with adjusted *p*-values indicated these were only significant when comparing Lepe and Southbourne with the Bournemouth and Southampton study sites for flights 'over a town or city centre' ($p > .05$) and 'over an industrial areas' ($p > .05$). Given Southbourne is a residential area and Lepe a countryside recreation area, these impacts are likely explained by people seeing logistics drones in quieter settings with less existing road traffic where they live and spend leisure time.

A further Kruskal-Wallis test compared responses from the five clusters identified in section 4.1. Flight frequencies were significantly affected by cluster membership for all over flight settings and pairwise comparisons with adjusted *p*-values showed differences related to cluster 3 ($p > .05$) which selected higher flight frequencies. Cluster 3 assumes environmental gains and delivery benefits, which are questioned in studies (Grote et al., 2024), and demonstrates how a positive view of benefits impacts the positive reception of over flights.

4.3 Discussion

The participant insights have implications for planning decisions and those tasked with governance and regulation of logistics drones. Participants raise delivery advantages and environmental benefits which are largely unproven assumptions. Cluster 2 focused on delivery benefits and almost all the mentions of medical use are in this cluster, however, studies are emerging that question the benefits of logistics drones in medical use cases as other factors limit the efficacy (Grote et al., 2023; Oakey & Smith, 2024: Sedig et al., 2020). Time saving, presented in terms of saving lives and as a societal benefit, is a prominent discourse in the grey literature on trials (see for example, Swiss Post Ltd, 2023), but may be very limited or superfluous to the task.

Cluster 3 focused on assumed environmental gains and delivery benefits linked with reduced congestion and energy savings that are well touted in trials and the media. However, given payload limitations of drones, the benefits are negligible as multiple trips are required to replace one van round (Oakey et al., 2022). Battery operated drones are zero tail pipe emissions, but only truly zero emissions when the electricity supply is renewable making them on a par with electric vans. There are also significant unanswered questions about the embedded energy in the technology and its disposal. Lastly, even island use cases are in question due to weather considerations (Oakey & Cherrett, 2023). As more rigorous evidence emerges on delivery advantages and environmental benefits this is likely to reposition thinking on logistics drones. Assuming less universal or socially desirable benefits and minimal environmental gains then those who are currently positive about drone deliveries are likely to shift their perspective, especially as some do express concerns.

Given the social desirability of some use cases and that participants assume a range of benefits, it is critical that decision makers carefully examine evidence that demonstrates cost, environmental, health or other advantages and are transparent about uncertainties and negative impacts. If use cases do not stack up, then a public backlash is likely given the concerns raised around noise and where drones might fly.

Hearing logistics drones has made noise a prominent issue. Vans are also noisy but constrained to roads whereas drones potentially have scope to move more freely in lower airspace bringing noise pollution to new spaces with greatest aversion to drone flights over residential areas, countryside and urban parks. Electric vans, in contrast, are very quiet at the low speeds of operation needed in residential areas. People also expect noise by roads and make choices about where to live based on this. Logistics drones could radically alter people's noise exposure. Addressing noise is therefore vital feedback to those responsible for developing regulation. Where logistics drones fly matters to people with respect to altitude, frequency, time of day and products carried. There is a need to differentiation between settings (housing, urban parks, city centres, industrial areas) due to annoyance to people, impacts on animals and wildlife, safety and accidents.

People were more averse to logistics drones where they live (homes, housing) and spend leisure time (countryside, urban parks), but less averse to drones over town centres where ground risk is typically higher. These results contrast with current logistics drone routing decisions based on ground risk (the probability of a drone hitting a person and injuring them if it fails in flight) (Pilko et al., 2023) and is an additional factor that regulators will need to consider. If use cases prove viable, logistics drones will be more prominent near distribution depots or sites like hospitals. If these are located close to housing or outdoor leisure sites, then significant local opposition would be a challenge and this needs to be factored into use case viability. As found by Thomas and Granberg (2023), flight paths need to carefully consider the impact on those living near or using the area beneath, alongside issues like ground risk, energy and time use. Linked to this, regulation of operators is important related to how they address safety, security and privacy.

In a democratic society where the population inputs into decisions, public views of logistics drones have implications at a national level for overarching regulations and at a local level for decisions about flight paths. While this study found some limited patterns relating to different study sites, these are likely to vary from place to place due to different local interests and the local value in using logistics drones. The VR approach provides a cost-effective way to explore views of logistics drones in different places.

5. Conclusion

This paper has demonstrated the value of using VR to involve people logistics drones. To fully benefit from AAM technologies, it is vital that governments and regulators understand how these technologies might differentially impact and benefit different places. Previous work with the public on drone technologies has been at an abstract level and often confounds different drone technologies. This study has explicitly contextualised logistics drones to places that people know and reached a diverse and comparatively large audience (n=371) that would not normally be engaged in transport consultations or research in a short timespan with limited resources. The VR enhanced people’s understanding of logistics drones and how they differ to other drones. This helped involve participants at a deeper level enabling articulation of nuanced views about a range of issues that went far beyond simplistic statements of acceptance or rejection. The VR extended thinking beyond preconceptions providing an opportunity to raise new issues and bringing different issues to the fore in contrast to previous studies. Furthermore, in contrast to trials, which are typically focused on medical logistics in the UK, the VR was agnostic about the items being delivered with a question on medical logistics illustrating the social desirability bias that such a use case yields. It was evident that participants had little or no exposure to, or understanding of, logistics drones and, while the VR helped, there is scope to augment the approach with further information about logistics drones. The team has subsequently developed an explainer video (XXXX *reference link to video anonymised for review*) for use in further research.

While VR has proved effective as a tool to involve people with logistics drones that is easier and much cheaper than a trial, there are upfront resource costs to develop the VR. Materials from the xxxx (*anonymised for review*) project are available for others to use along with the code and instructions to build on the current work to minimise future resource costs. VR is a cost-effective solution to involve local people in decision making about AAM initiatives that could be readily deployed in other places where local governments and other regulators maybe making decisions about drone flight paths, altitudes and frequencies.

In further research, noise levels need to be addressed by researchers and technology developers. There is both a need to reduce the noise pollution generated by logistics drones and to undertake research to define noise thresholds according to different settings, use scenarios, altitudes, and flight frequencies. There is also a need for more research to determine the actual benefits of logistics drones. Trials need to build in a much more considered analysis of the product movement requirements (for example, addressing questions of need and urgency), delivery contexts, energy use and timescales while making clear comparisons to current delivery systems (for example, will the vans still have to deliver other items? Are other vehicles available that could consolidate products with other items? Would other modes offer advantages?). This study has used VR to take logistics drones to different places. This has shown that views of where drones should fly varies depending on the setting being flown over. There is a need for further work to test out responses in urban parks, varied housing and industrial settings together with different rural locations (for example, small towns, villages and agricultural land).

Funding: This work was supported by the Engineering and Physical Sciences Research Council, United Kingdom [grant number EP/V002619/1] and by Future Flight Social Insight funded by the Economic and Social Research Council and Innovate UK.

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Appendix A: Technical details of VR development

The virtual environments were realised in Blender 3.x digital graphics modelling and imaging software. They were presented on Oculus Quest2 head mounted displays, as VR180 format videos (stereoscopic pairs on an 8192x4096 resolution image). Other software packages used in the production pipeline were GIMP 2.10 for image editing, Audacity 3.x for audio processing, Shotcut 23.x for video editing and Topaz Gigapixel AI 6.10 for further image processing. These packages are open source with the exception of the Topaz proprietary software.

The 3D multi-rotor drone design was adapted from the Motion Robotics Neptune OBJ drone and the 3D fixed-wing hybrid drone design adapted from the V44/50 STL

(Skylift, 2023). All source designs were either used with permission or allowed for academic use.

The VR was designed to include realistic logistics drone sound. The audio was developed using two main sources: field drone recordings (both fixed wing and rotary bladed) by the authors, as well as sound supplied from Southampton University's Valerie fixed-wing drone. The recording instrument was a Zoom HR3 VR microphone which was fitted onto the leg struts of the drone in each case. Audio was embedded into the VR with volume adjusted relative to heights and distances with the sound fading in and out as a drone approaches and passes by. The drone sound was provided through headset speakers rather than headphones, so participants were also exposed to the ambient noise of the outdoor study location. While the final drone audio was perceived by the team to be realistic, it is acknowledged that it is difficult to calibrate the sound level in a VR headset and this is an area for further work.

The location imagery for the drone flights was captured using a VuzeZR camera which provides an 180^0 3D image of each study site. The image was captured in the position where participants were to take part, so on wearing the VR headset, participants could see the actual view in front of them. The backdrop capture reflected a seated height as participants wore the headset seated in case of any disorientation response to the VR. The backdrop criteria were that there should be an open central space, with no obscuring structures too close to the camera (within 3 meters) and an open expanse of sky to allow views of the drones in flight.

Appendix B: Questionnaire

Initial thoughts about delivery drones

1) What are your initial comments on the use of drones for making deliveries?

Where should delivery drones fly?

Drones like those you have just seen in the Virtual Reality headset could be used in the future to make regular deliveries in the UK. Early-stage delivery services would operate along fixed flight paths using pre-determined landing sites.

2) Which settings do you think it would be appropriate for delivery drones to fly over?
Tick the frequency option you feel is most appropriate for each setting.

	No drones	No more than four drone	A drone flying over	A drone flying over	A drone flying over

	flying over	flights a day	every hour	every 30 minutes	every 15 minutes
Over an area of housing	☐	☐	☐	☐	☐
Over a town or city centre	☐	☐	☐	☐	☐
Over an industrial area	☐	☐	☐	☐	☐
Over an urban park	☐	☐	☐	☐	☐
Over countryside[1]	☐	☐	☐	☐	☐
Over my home	☐	☐	☐	☐	☐

Using drones to deliver medical items[2]

Early work on the use of drones for making deliveries has focused on moving urgent medical items to support the work of the NHS.

3) In which settings do you think it would be appropriate to operate medical delivery drones?

   Tick the frequency option you feel is most appropriate for each setting.

	No drones flying over	No more than four drone flights a day	A drone flying over every hour	A drone flying over every 30 minutes	A drone flying over every 15 minutes
Over an area of housing	☐	☐	☐	☐	☐
Over a town or city centre	☐	☐	☐	☐	☐

Over an industrial area	☐	☐	☐	☐	☐
Over an urban park	☐	☐	☐	☐	☐
Over my home	☐	☐	☐	☐	☐

Your thoughts on delivery drones:

The Government funded Future Flight Challenge is looking at how the use of drones for deliveries might become a reality in the UK over the next few years. We have provided an introduction to this idea using the Virtual Reality headset and would like to get your views to help inform further research and future decision making.

4) Delivery drones navigate by GPS and can fly just as well at night. What are your thoughts on delivery drones operating at night?

5) What feedback would you give to those responsible for developing regulation?

6) What additional information would you like to help you develop your viewpoint on this?

About you

7) How much, if anything would you say you know about drones? (Select one answer)

Hadn't heard of them before now	
Hardly anything but I have heard of them	
A little	

A fair amount	
A lot	
Don't know	

8) Have you ever personally used a drone? (Select as many as apply)

Yes, used one personally	
Yes, used one for commercial or work-related reasons	
No	

9) What is your gender?

10) What is your age group? (Select one answer)

18-24	
25-34	
35-44	
45-54	
55-64	
65-74	
75-84	
85 and over	

11) What is your ethnic group? (Select one answer)

1) White English/Welsh/Scottish/Northern Irish/British	
2) White Irish	
3) White Gypsy or Irish Traveller	
4) White Any other White background, please describe	
5) Mixed White and Black Caribbean	
6) Mixed White and Black African	
7) Mixed White and Asian	
8) Any other Mixed/Multiple ethnic background	
9) Asian or Asian British Indian	
10) Asian or Asian British Pakistani	
11) Asian or Asian British Bangladeshi	
12) Chinese	
13) Any other Asian background	
14) Black African	
15) Black Caribbean	
16) Any other Black/African/Caribbean background	
17) Arab	
18) Other (please add details below)	

12) What is your employment status? (Select as many as apply)

Employed full-time	
Employed part-time	
Self-employed full-time	
Self-employed part-time	
Looking after home/family	
Unemployed	
Permanently sick/disabled	
Full-time student	
Retired	
Other	

13) What is the highest level of education that you have completed? (Select one)

No formal qualifications	
O-Level/ CSE/ GCSE	
A-Level or equivalent	
Higher National Diploma or equivalent	
University degree or equivalent	
Post-graduate qualification	
Other	

14) What is your home postcode?

Thank you! Please hand your completed survey to the researcher.

Notes
[1] additional setting introduced at Lepe Country Park and Southbourne study sites
[2] medical use case not used at Lepe Country Park and Southbourne study sites