



# A Systematic Scoping Review of Human-Dog Interactions in Virtual and Augmented Reality: The Use of Virtual Dog Models and Immersive Equipment

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Virtual reality is beneficial from a research and education perspective as it allows the assessment of participants in situations that would otherwise be ethically and practically difficult or impossible to study in the real world. This is especially the case where the assessment of human behaviour in the presence of stimuli (e.g. an aggressive dog) is being measured which could potentially constitute a risk in a real-world environment (e.g. a dog bite). Given that the dog is the most popular companion animal species, to date there is limited research that identifies and reviews the use of virtual and augmented reality directly relating to human-dog interactions. Furthermore, there also appears to be no review of the equipment and dog model specifications, such as dog breed and behaviours, which are currently used in these studies. As a result, this systematic scoping review searched ten databases to assess the current use and specifications of dog models which directly focused on human-dog interactions. Ten articles were identified. Six related to assessment or treatment of dog fear/phobia (cynophobia), three included multiple animal phobias, including dogs, and one article investigated the human and virtual dog interactions whilst walking. Six articles used a single breed (German Shepherd, Beagle, Doberman, and Rottweiler). Both the breed and behaviours displayed lacked justification and were often not evidence based. Specific measurements of model quality (e.g., polygons/vertices) were reported in only two articles which may affect repeatability and make comparisons between studies difficult. The virtual reality equipment (e.g. CAVE, head mounted display) and navigation methods (e.g. joystick, mouse, room scale walking) used varied between studies. In conclusion, there is a need for the accurate development and representation, including appearance and behaviours, of dog models in virtual and augmented reality. This is of high importance especially as most of the research covered in this review was conducted with the aim to treat the fear or phobia of dogs.

**Keywords:** dogs, model, human-dog interactions, virtual reality, augmented reality, dogs (*Canis familiaris*)

## INTRODUCTION

Pet ownership in the United Kingdom is popular: as of 2020, 59% (17 million) of households owned a pet animal, the most popular species being dogs (33% of households; 12.5 million dogs) (PFMA, 2021). Companion and service/therapy/assistance dogs are suggested to provide a range of physical benefits (e.g., increased exercise and physical activity) and psychological benefits (e.g., reduced loneliness and depression, aids in social facilitation) to owners (see reviews by Sachs-Ericsson et al., 2002; Friedman and Krause-Parello, 2018; Gee and Mueller, 2019; Wells, 2019). Given our affinity and interactions with animals, it is therefore not surprising that they have been incorporated via entertainment and gaming technology into virtual pets for commercial purposes.

Over the past 30 years, pets have been replicated by technology including virtual (2D) and robotic pets. These can be either “realistic” or “unrealistic”. Realistic pets are based on the appearance and/or behaviour of a real animal, e.g., Nintendo dogs (a virtual pet dog); AIBO (artificial intelligence robot, a robotic dog), and Lakaigo (a robotic dog imitating the locomotion of a real dog). Unrealistic pets do not fully resemble real-life animals but may have similar characteristics, e.g. Furby (a robotic pet); (Laureano-Cruces and Rodriguez-Garcia., 2012; Bylieva et al., 2020; Rativa et al., 2019; Peng et al., 2020). The traditional market for virtual pets, whether implemented as quickly as games or robots, is mainly children. Children use virtual pets for the purposes of: 1) entertainment; 2) learning how to take care of a pet (e.g., walking, feeding, etc., where the pet deteriorates in the absence of care), without the cost associated with real pet ownership; 3) companionship (Luh et al., 2015). However, virtual dogs (e.g., Nintendo dogs) can stimulate emotion and emotional attachment in users (e.g., Weiss et al. (2009) found that children made an emotional attachment with a robotic dog, AIBO) (Laureano-Cruces and Rodriguez-Garcia, 2012; Bylievia et al., 2020), but invariably do not offer the same level of companionship to that of a real pet might provide (Chesney and Lawson, 2007). Comparing social affordances between a stuffed dog and a virtual dog, the stuffed dog was associated with friendship and the virtual dog being associated with entertainment (Aguiar and Taylor, 2015). More recently, Lin et al. (2017) conducted a survey of 774 individuals who played games that included a virtual companion (e.g., Nintendo dogs) and found the main reason for playing was because the individual could not own a real pet (e.g., due to allergies) and virtual companions were deemed a form of emotional support.

In addition to entertainment, virtual dogs have a use in public health and education. Research has been undertaken into the use of virtual dogs for children as a means of increasing breakfast (Byrne et al., 2012) and fruit and vegetable consumption (Ahn et al., 2016) and promoting physical activity (Ruckenstein, 2010; Ahn et al., 2015; Hahn et al., 2020), increasing attitudes and empathy (Tsai and Kaufman, 2014), reducing obesity (Johnsen et al., 2014) and promoting effort making behaviours in learning (Chen et al., 2011). More recently, virtual animals have also been incorporated into mobile gaming apps (e.g., Pokémon Go) and have been found to be beneficial for human physical and

psychological health. For example, Kogan et al. (2017) found that Pokémon Go usage increased the time spent with family members, walking their own ‘real’ dog, and exercising, as well as reducing anxiety levels.

As a result of recent technological advances, increased availability and the significant reduction in cost of equipment, the use of Virtual Reality in research has increased (Slater, 2018). The term “virtual reality” (VR) refers to a simulated three-dimensional environment in which a user can be psychologically immersed through VR or AR (Augmented Reality) technology [such as an HMD (Head Mounted Display) or CAVE (Cave Automatic Virtual Environment)], and interact with the environment, through visual, auditory and haptic feedback (Virtual Reality Society, 2017; Johnston, 2018). VR provides a range of benefits such as user immersion and presence in the environment, the ability to potentially interact with a virtual object (such as a pet), the ability to elicit an increased degree of emotion, and the viewing area is much greater compared to 2D formats and is often, but not always, controlled by natural user movement (Lin et al., 2017). However, the degree of immersion, presence, perceptions and interactions in VR may be influenced by a variety of factors such as equipment, user’s knowledge and experience, virtual environment, model development and appearance/quality/realism (e.g., the “Uncanny Valley” as previously seen using realistic and unrealistic images of cats and dogs) (Yamada et al., 2013; Lin et al., 2017; Schwind et al., 2018).

There has been development of VR and AR applications for public entertainment. For example, in the VR game “The Lab–Postcards”, released in 2016 by the Valve Corporation, a user can interact with a virtual robotic dog (fetch-bot) including haptic feedback upon contact with the dog and throwing a stick which the dog retrieves (Lin et al., 2017). More recently, as with Nintendo dogs in 2005, an AR mobile application dog “Dex” has recently been developed where users can walk, feed, play and look after their pet dog in AR (see Labrodex Studios, 2019).

More specifically, virtual animals may be of use in addressing public health outcomes directly related to contact with animals. For example, hospital admissions in England as a result of dog bites are increasing (Tulloch et al., 2021a) causing significant physical injury and interventions to prevent these occurring are required. Dog bites can also result in ASD (acute stress disorder) or PTSD (post-traumatic stress disorder) (Peters et al., 2004; Ji et al., 2010). VR animals developed for research and treatment of human participants exist. For example, the use of VR and/or AR for animal phobias, in the form of exposure therapy, is well established and includes a range of species such as spiders (Miloff et al., 2016; Tardif et al., 2019), cockroaches (Botella et al., 2010), dogs (Farrell et al., 2021), multiple small animals (Quero et al., 2014; Suso-Riber et al., 2019) and animals in general (zoophobia) (Suárez et al., 2017). Additionally, software companies also provide animals models for health care professionals for the treatment of various phobias (dogs, cats, snakes, spiders) [e.g. see InVirtuo (<http://invirtuo.com/>)].

The use of VR, in animal simulations has animal and human welfare implications. It may often be more ethical (i.e., no live animals used) and practical (i.e., one has control over a virtual

stimuli/environment). In addition, it is a more affordable alternative to the use of live animals whilst allowing for repeated treatments (Farrell et al., 2021). Examples, where this is the case, include, animal-assisted therapy (Ratschen and Sheldon, 2019) (e.g., the Dolphin swim club <https://thedolphinswimclub.com/>), dog phobia treatments (Farrell et al., 2021) and animal dissections (Lalley et al., 2010).

Despite the latter benefits, to the authors' knowledge, there has been no scoping review on the current use, efficacy, advantages and disadvantages of the use of dog models in VR and AR. Here we focus specifically on a scoping review of direct human interactions with VR and AR dog models and the consideration and representation of the models physical appearance (i.e., breed) and behaviours displayed. The accurate representation of dog models and their behaviours is important, especially where they are used for injury prevention (e.g., education) and/or post-injury mental health treatment (e.g., phobia treatment).

Dog bites are often described as being "unprovoked" (Love and Overall, 2001), however, this is often not the case as evidence indicates that dogs show a range of behaviours before a dog bite occurs indicating stress, ranging from subtle "appeasement" signals (e.g., lip licking, yawning) that individuals may be less aware of to those that are more obvious (e.g., growling, showing teeth, barking) (Shepherd, 2009; Owczarczak-Garstecka et al., 2018). Therefore, the accurate representation of evidence-based dog behaviours is important from a public health viewpoint. Further, to ensure that the successful treatment of dog phobia occurs an individuals' understanding and recognition of dog behaviour is important (e.g., when to and when not to approach a dog in the real world based on behavioral signals). Furthermore, in the context of dog bites and aggression, the public media is often negatively biased towards specific dog breeds (e.g., bull breeds) (see review Kikuchi and Oxley, 2017) and this may influence public opinion. Therefore, exploration of breeds chosen and their contexts in VR and AR is important to evaluate.

If effective use of VR animal models is to be applied to real-world situations, an evidence-based approach is needed. Therefore, this review aims to:

- 1) Explore the scope of the field in which VR/AR dog models have been used in research with the focus directly on human-dog interactions.
- 2) Describe the representation of virtual dog models (e.g., appearance/breed) and dogs behaviour including evidence-based development and fidelity.
- 3) Identify what equipment is used and if/how these differ between studies.
- 4) Describe the main findings of the research and measures used, both objective and subjective, to assess the human-dog interaction and other measures used in VR.

## METHODS

This scoping review adhered to PRISMA (Preferred Reporting of Items for Systematic Reviews and Meta-Analyses) guidelines and methodology (Moher et al., 2009).

## Identification of Relevant Studies and Search Criteria

Literature from a 30-year period (January 1990–September 2020) was reviewed due to the rise in the popularity of VR from the 1990s and the invention of CAVE (Cave Automatic Virtual Environment) in 1992 (Cruz-Neira et al., 1992). Data collection occurred on the 9th and 10th of October 2020.

Due to the multidisciplinary nature of research articles using VR and AR dog models, ten databases were searched, covering psychology (APA), veterinary science (CABI direct), medical and veterinary (Cochrane library, PubMed, Medline), technology, computing, and engineering (IEEE, ProQuest) fields, in addition to the large databases; Scopus, Web of Science, and Google Scholar. In addition, to database searches, references from relevant articles were identified by reviewing these manually.

The search terms were used to identify relevant articles using the article title, abstract and/or keywords are given in **Table 1**.

Peer-reviewed journal articles and conference articles were included in the search findings but not editorials, commentaries, reviews (**Table 2**). Conference articles were included due to the recent emergence of this area of research and several relevant conference articles specifically focusing on human interactions with a VR or AR dog model (e.g., Hnoohom and Nateerataiwa, 2017; Norouzi et al., 2019).

## Behavioural Dog Models

Articles included in the review are displayed in **Figure 1**. All articles involved dog models which displayed some form of behaviour and focused on direct interaction between the human and virtual dog. The first category of articles, for exclusion from this study, consisted of indirect VR dog model use; the dog model was not part of the main purpose of the study. Examples include, haptic forces used for rehabilitation through the use of simulated dog walking (Sorrento et al., 2018), used to facilitate the study (e.g., leads or assists the users to an area as part of a non-dog related study/task (e.g., Hung et al., 2018)) or study conditions (e.g., a red robot dog that barked to distract the user (Rewkowski et al., 2019)). Articles were excluded if they were in 2D due to the reported disadvantages when compared to 3D VR including reduced levels of presence, immersion, and spatial navigation success rates (Slobounov et al., 2015; Minns et al., 2018). Articles with the use of mobile phones were only included if they consisted of 3D VR/AR with an HMD as they are likely to provide a similar VR experience (e.g., stereoscopic vision, enclosed eyes). The second category, for inclusion in this study, was direct VR dog model use; the dog model was a key part of the study with direct focus and involvement of, and/or interaction with, the dog model (e.g., phobia treatment) (**Figure 1**).

## RESULTS

In total ten articles were found to directly research, or propose future research, human interactions with virtual dog models using a VR or AR set up. Despite the initial 30-year inclusion period, all articles were published from 2008 onwards (**Table 3**).

**TABLE 1** | Search terms used for title, abstract or key words. Acronyms being used for Augmented Reality (AR) and Virtual Reality (VR) were originally included, but due to the broad alternative use of AR (e.g., AR protein/gene expression, androgen receptor, allergic rhinitis; allelic ratio, anterior right) searches were conducted separately and initially reviewed for each database but no new articles were identified.

#### Search terms

("Virtual Reality" OR "Virtual Environment" OR VR OR "Mixed Reality" OR "Augmented Reality") AND ("Companion animal" OR "companion pet" OR "pet animal" OR pet OR pets OR dog OR dogs OR canine OR cynophobi<sup>a</sup>)

<sup>a</sup>Asterisk indicates plural terms (e.g., cynophobic or cynophobia).

**TABLE 2** | Inclusion and exclusion criteria for literature search.

Category	Inclusion Criteria	Exclusion Criteria
<b>Time Frame</b>	January 1990–September 2020	Articles outside this time frame
<b>Language</b>	English articles only	Articles that are not written in English
<b>Article Type</b>	Peer reviewed journal articles, Conference articles (including prototypes and research articles)	Reviews/discussion articles, review/discussion conference papers, abstracts only, editorials, letters, thesis/dissertation
<b>Equipment used</b>	VR and AR HMDs (including smartphone HMDs (e.g. google cardboard), CAVE/Screen	Mobile phones/tablets that are used on their own without an HMD.
<b>Literature focus</b>	All articles which include a VR representation of a live pet dog that displays behaviours and is the focus of the article	Human-dog interactions is not the focus of the study. VR robotic dog models, anatomical models, 2D dog models, real dogs and/or non-dog animal models. Software/technical development with no reference to VR.

Nine articles included some form of results from participants [mean sample size = 13.2 (range: 6–32)]. One article described the development of VR animal models (including dogs) for future use to treat phobic participants but did not report research with participants (Maglaya et al., 2019).

## Areas of Research and Measures

Nine out of the ten articles specifically focused on the topic of the development of a VR dog model to stimulate emotions or the proposed or actual treatment of individuals who were fearful or had a phobia of dogs (cynophobia) (6/9) or multiple animal phobias (i.e., zoophobia) which included cynophobia (3/9). One article targeted non-phobic individuals to investigate the proximity to and collision between an AR dog model and a human who was walking the dog.

Nine studies recorded some form of subjective measurement, with the most commonly used being the Subjective Units of Distress Scale, some form of presence measurement (e.g., Igroup questionnaire) and a subjective Behavioural Assessment Test. One study recorded biological/physiological measurements including skin conductance (Taffou et al., 2013). Another article briefly mentioned that measurements of heart rate, anxiety and sweating were recorded but no further details were provided (Suárez et al., 2017) (Table 3).

## Main Findings

Research articles mainly focused on the evocation of fear and the treatment of fear and phobias through VR dog models. It was evident that the dog models resulted in an increase in fear, distress, anxiety, and behavioural responses. Audio, where recorded, in the form of dog vocalisations (e.g., growling, barking) also appeared to increase fearfulness of the dog. Of those studies which specifically used the dog model as part of a dog fear or phobia treatment, these often result in reduced fear or

phobia (Table 3). For example, in one article 75% of children were deemed as recovered 1 month after treatment (Farrell et al., 2021).

## Equipment

Equipment varied from four studies using a AR/VR HMD (e.g., Oculus Rift) and five articles using a projection screen (single or multiple screens (e.g., CAVE/BARCO Ispace/Blue room)). Out of the nine articles where the user navigation/control method was stated, six used a hand controller (e.g., mouse, joystick, game controller, remote control), one article a therapist controlled the movement through a tablet, one article there was room scale movement for the user and one article it was unclear the if the user navigated or moved their head only (i.e., 3DOF or 6DOF) (Table 4).

## Dog Models

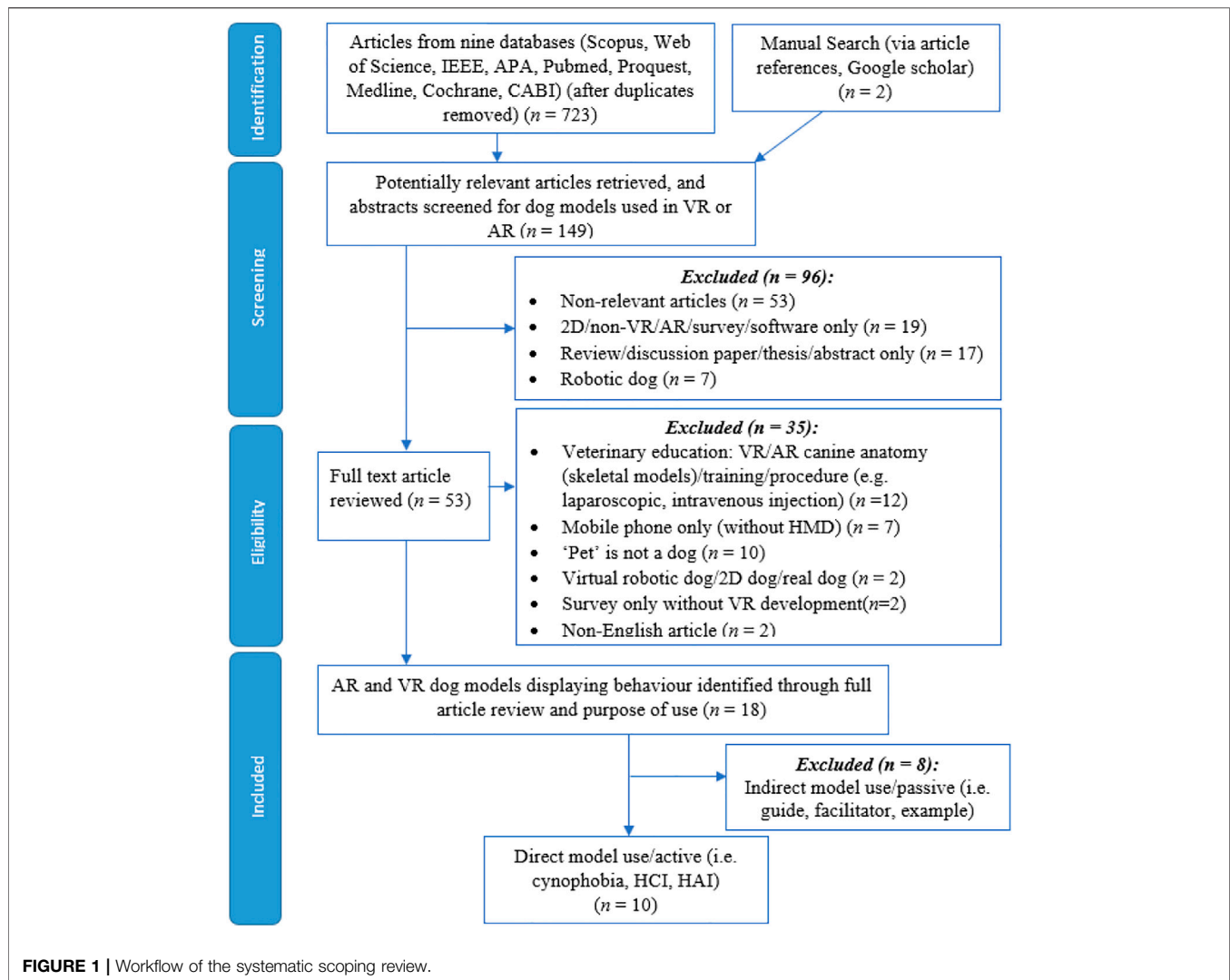
### Breed, Coat Colour and Behaviour

Seven articles stated the breed of the dog model used which included six studies using a single breed [German Shepherd, Beagle, Doberman (3), Rottweiler] and one study which included videos of multiple breeds (Cocker Spaniel, Labrador x Kelpie, Rottweiler x Border Collie, Cavoodle, Japanese Spitz). Where a single breed was used, in some cases different colours and textures of the models were included (see Table 5). There was a lack of justification and/or scientific evidence for the dog behaviours displayed and were often predefined prior to purchase of the model. The number of behaviours displayed often varied between studies and limited detail about the behaviours was provided (see Table 5).

### Dog Model Quality

The quality of the virtual dog models in terms of polygon or vertices count was not mentioned in any article. In one case there





was a web link to a pre-defined dog model which highlighted the number of polygons via an external website (Table 5). In one study investigating multiple phobias, the dog model was described in very little detail and therefore unlikely to be replicated in future research (Maskey et al., 2019). Another study used 360-degree video footage of real dogs in conjunction with a VR headset and separate assessments with the use of real dogs (Farrell et al., 2021).

## DISCUSSION

The aim of this review was to identify and assess research that directly involved the use of human interactions with dog models in VR and AR. To the authors knowledge this is the first scoping review specifically identifying and assessing human interactions with VR and AR dog models, model quality, behaviours displayed, and equipment used. Findings from this review highlight that although research using VR is well established, the development and use of VR and AR dog models for the

purpose of human-dog interaction assessment is in its infancy. The use of VR dog models as a form of exposure therapy had positive effects. However, there was variation in the study sample size, VR equipment used and the behaviours displayed by the virtual dog, which tended to lack an evidence-based approach to the development of a canine model in relation to canine behaviour.

## Equipment

There were several different VR HMD's and screen-based systems identified. Changes and advances in technology are inevitable. Furthermore, as technology improves other forms of HMD's become outdated and are no longer used which highlight the importance of stating technical specifications of all equipment used in research with VR models. This should include:

- VR equipment (HMD/Screen/CAVE) specifications: Navigation method, whether the VR HMD is 3DOF or 6DOF, HMD specifications (resolution, refresh rate, field of view, tethered or wireless), tracking (outside in or inside

**TABLE 3** | Reviewed articles involving the direct use of an VR or AR dog model, their sample size, subjective and objective measures and main findings. (Asterisk (\*) denotes research from the same research group).

Topic	AR/VR/Author/ Article type	Aims	Study type/Sample/M/F	Subj. Measures	Task & Obj. Measures	Main findings
Cynophobia/fear of dogs	VR  Viaud-Delmon et al. (2008)*  Conference paper	<i>"The primary aim is to determine the situations in which emotional reactions can be evoked in individuals who fear dogs. A secondary aim is to test the efficacy of progressive exposure . . . that can be manipulated in VR only (e.g. . . . dog behavioural control . . .)"</i> (p.2)	Preliminary/pilot study  Fear of dogs screening survey (n = 75) (43M/32F)  VR study (n = 10) (M/F: n/a)	<b>(Proposed but not reported)</b> <ul style="list-style-type: none"> <li>• Fear of dogs questionnaire</li> <li>• Subjective Units of Distress (SUD) Wolpe, (1973)</li> <li>• State Trait Anxiety Inventory (STAI) Spielberger et al. (1983)</li> <li>• Cybersickness scale Viaud-Delmon et al., (2000)</li> <li>• Presence Igroup scale Schubert et al. (2001)</li> </ul>	<b>Task:</b> Participants were required to locate targets by following a trajectory where dogs were present in a gradual exposure format  <b>Behavioural:</b> <i>"...count the behavioural reactions of the participants whenever they encounter a dog (step backward, freezing . . .)"</i> (p.4)	<b>(Descriptive results only) Fear of dogs screening</b> - The Doberman was deemed the breed which evoked the most negative emotion. The size of the dog had an impact on participants emotional reaction  <b>VR study</b> - Participants focused on emotional stimuli (e.g. dog) rather than lighting conditions Dog barking and growling resulted in high anxiety
	VR  Taffou et al. (2012)*  (Note: Sub-sample of Taffou et al. (2013) results) Book Chapter	<i>"This study aims to precisely assess the impact of multi-sensory stimulation on fear reactions."</i> (p.238)	Fear of dogs Screening survey (n = 110)  (66M/44F) VR study (n = 11 took part but only 9 completed due to cybersickness) (M/F: n/a)	<ul style="list-style-type: none"> <li>• State Trait Anxiety Inventory (STAI) Spielberger et al. (1983)</li> <li>• Cybersickness survey Viaud-delmon et al. (2000)</li> <li>• Igroup presence questionnaire Schubert et al. (2001)</li> <li>• Subjective Units of Distress (SUD) Wolpe, (1973)</li> </ul>	<b>Task:</b> Training session and two Behavioural Assessment Tests (BAT) session involving a virtual dog showing different behaviours with a gradual increase (unimodal and static, unimodal and dynamic, audio-visual and static, audio-visual dynamic). Participants had to explore the area to find a green frog  <b>Behavioural:</b> BAT (score 0–14 (0—participant did not want to enter the VR space; 14—participant put their face against the virtual dog's face for >5s)	No sig. difference between two exposure sessions and both BAT scores Sig. higher ( $p < 0.01$ ) SUD score in bimodal session compared to unimodal session  Two participants did not complete due to cybersickness  —
	VR  Suied et al. (2013)*  Paper	<i>"The primary aim of the current study is to identify the situations in which emotional reactions can be evoked in individuals who fear dogs. A secondary aim is to test the impact of features that can be manipulated in VR only"</i> (p.145)	Fear of dogs screening survey (n = 115) VR study (n = 10) (4M/6F)	<ul style="list-style-type: none"> <li>• State Trait anxiety Inventory (STAI) Spielberger et al. (1983)</li> <li>• Cybersickness survey Viaud-delmon et al. (2000)</li> <li>• Igroup presence survey Schubert et al. (2001)</li> <li>• Subjective Units of Distress (SUD) before and after immersion Wolpe, (1973)</li> <li>• Apprehension of virtual dog (3 point scale: 1—not afraid, 2—quite afraid; 3—very afraid)</li> <li>• Fear of dogs questionnaire</li> <li>• Diagnostic interview</li> </ul>	<b>Task:</b> Participants were asked to explore the area to find a green frog which was visual and produced sound and found in the surroundings of the dogs  <b>Behavioural:</b> Behaviour ratings of the user in the presence of a virtual dog (scale 1–6 (1—dog not noticed to 6—dog noticed and flight or freeze))	Sig. Higher ( $p < 0.01$ ) STAI scores between after VR exposure  Virtual dogs evoked a verbal and behavioural reactions (rating median score range 2–5 when exposed to 4 virtual dogs) Dog colour and audio influenced participants reaction. Most reactive to the growling dog with a dark coat Presence Igroup presence survey (score range 0–88) noted as "satisfactory" (mean score: 43.5; SD: 17.6). Presence scores positively correlated with apprehension of dogs and SUD scores Cybersickness symptoms were reported (Continued on following page)

**TABLE 3 |** (Continued) Reviewed articles involving the direct use of an VR or AR dog model, their sample size, subjective and objective measures and main findings. (Asterisk (\*) denotes research from the same research group).

Topic	AR/VR/Author/ Article type	Aims	Study type/Sample/M/F	Subj. Measures	Task & Obj. Measures	Main findings
	VR	"...our goal was to manipulate the presentation of auditory and visual aversive stimuli in order to investigate whether the multi-sensory presentation influences the conscious experience of fear." (p.348) "Thus, we created a paradigm aiming at investigating the conscious experience of fear in the most appropriate and natural manner" (p.350)	Fear of dogs screening survey (n = 225)	<ul style="list-style-type: none"> <li>• Dog phobia questionnaire Viaud-Delmon et al. (2008)</li> <li>• State Trait Anxiety Inventory (STAI) Spielberger et al. (1983)</li> <li>• Cybersickness survey Viaud-delmon et al. (2000)</li> <li>• Igroup presence questionnaire Schubert et al. (2001)</li> <li>• Subjective Units of Distress (SUD) Wolpe, (1973)</li> </ul>	<b>Task:</b> Training session and two BAT sessions involving a virtual dog showing different behaviours with a gradual increase (unimodal and static, unimodal and dynamic, audio-visual and static, audio-visual dynamic, low visual contrast). Participants had to explore the area to find a green frog <b>Biological:</b> Skin Conductance (hands) level (pre and post immersion) <b>Behavioural:</b> BAT (score 0–14 (0 - participant does not want to enter the VR space; 14—participant put their face against the virtual dog's face for >5 s)	Sig. higher (P< 0.01) SUD score in bimodal compared to unimodal session for both non dog and dog fearful groups
	Taffou et al. (2013)*  Paper		Interview (n = 22) (12F/10M)  VR study (high dog fearful (9) and no/low dog fearful participants (10) (n = 21 (9M/12F) but only 19 completed due to cybersickness).			No sig. diff. between unimodal SUD between indoor and outdoor VEs In the high dog fear group, sig. higher SUD ratings (p = 0.008) were given for the dog growling than to the dog barking. No sig. diff. between growling and barking in the no/low fear group Two participants did not complete due to cybersickness
	VR	"In this paper we propose a virtual reality-based smartphone application for user exposure to face their animal fear phobia."	Prototype and survey (n = 10) (5M/5F)	<ul style="list-style-type: none"> <li>• Survey includes questions regarding age, gender, VR experience and fear of dogs</li> <li>• Four-point Likert scale ("Few, average, much, very much"): Realism of application, "dreadfulness" of the dogs in three levels, sound, animation, and distance between the player avatar and dogs</li> </ul>	<b>Task:</b> Participants explored three zones resembling a garden and house. Zone 1) A dog is asleep and wakes up if the user comes near the dog; 2) A dog in a cage faces and growls at avatar and finally attempts to attack user when near the dog; 3) Same as zone two but not in a cage and the dog runs, jumps and attacks the user <b>Behavioural:</b> Not stated	<b>(Descriptive results only)</b> A dog model and environment were developed 50% of participants rated the free-standing dog in the back yard the most "dreadful" followed by the dog in a cage and the dog in the house 30% rated the following statement as "much" and 60% "average". "Hearing the dog sounds made us more fearful"
	Hnoohom and Nateeraitaiwa (2017) Conference paper					
	VR	"...whether VR OST results in clinically significant improvement for children with a specific phobia of dogs using a controlled, multiple baseline case series design where participants are randomly assigned to 2-, 3- or 4-weeks baselines, followed by the VR OST and a 1 month follow-up." (p.4)	Multiple Baseline (2, 3, 4 weeks) case Series VR study (n = 8)	<ul style="list-style-type: none"> <li>• Anxiety Disorders Interview Schedule: Parent (ADIS-P) Silverman and Albano, (1996)</li> <li>• Fear Survey Schedule for Children-Revised Child Version (FSSC-R-C) Ollendick, (1983)</li> <li>• Spence Children's Anxiety Scale Child &amp; Parent (SCAS-C/P; Spence, (1998)</li> <li>• Subjective Units of Distress (SUD) Wolpe, (1973)</li> <li>• Reality of VR stimuli 5-point scale (0—not at all like real life; 4—very real)</li> </ul>	<b>Task:</b> Behavioural Assessment Tests (BAT) (pre and post VR and 1 month follow up): Enter through a door into a room, approach and stroke a real dog (on a lead with handler) for 20s <b>VR exposure task:</b> Steps 1–10 (1—dog on lead w/handler walk into opposite side of the room; 10—dog in room off lead without handler) <b>Behavioural:</b> BAT (0—didn't open the room to the door; 10—completed the test)—pre-treatment, post treatment and 1 month follow up	75% (6/8) children were deemed "recovered" one-month after VR treatment 87.5% (7/8) were able to complete the BAT (approaching and patting a real dog) task one-month post VR treatment No significant decrease in anxiety or fear throughout the study for children
	Farrell et al. (2021)  Paper		(4M/4F; Children)			

(Continued on following page)

**TABLE 3 |** (Continued) Reviewed articles involving the direct use of an VR or AR dog model, their sample size, subjective and objective measures and main findings. (Asterisk (\*) denotes research from the same research group).

Topic	AR/VR/Author/ Article type	Aims	Study type/Sample/M/F	Subj. Measures	Task & Obj. Measures	Main findings
<b>Multiple phobias/ Zoophobia (incl. Dogs)</b>	VR Suárez et al. (2017) Conference paper	"the objective of this project is to provide a reasonable alternative for treating various types of Zoophobias, using virtual reality" (p.1)	Preliminary/pilot (n = 6) (M/F not stated)	<ul style="list-style-type: none"> <li>• "Laboratory tests were performed with the experimental group using virtual reality and traditional therapy with the control group. In each patient, five sessions and two levels of complexity were performed." (p.5)</li> </ul>	<b>Task:</b> Five sessions and two levels per person—No further detail provided. "The clinical status of the patients involved in the tests had symptoms of high heart rate, numbness, excessive sweating and anxiety" (p.5)	"After the session of the fifth practiced patients treated with VR, although the symptoms did not disappear completely, an 80% decrease in anxiety, sweating and heart rate was observed in all cases; While patients in the control group treated with traditional therapy, they had a 35% reduction for the same symptoms." (p.6)
	Paper (prototype) Maglaya et al. (2019)	"In this study and development, VR will be used as a tool to aid psychologist and psychiatrists in assessing and treating the different fear levels of patients"(p1.39)	Prototype  VR development for multiple animals (incl. dogs, spiders) and other phobias (claustrophobia)	<ul style="list-style-type: none"> <li>• Not applicable—prototype</li> </ul>	<b>Task:</b> Not applicable - prototype	Proposed usage for multiple animal phobias "Cynophobia: The patient will be situated inside a house. Lower levels of experience will involve sounds coming from a dog. The next level will be a shadow of a dog outside the window. The next level will be a dog on a leash slowly getting closer to the patient until the patient can touch the dog" (p.140)
	VR  Maskey et al. (2019) Paper	"... aims were to 1) evaluate treatment delivery feasibility, with fidelity, by therapists from two United Kingdom National Health Service (NHS) teams; (2) determine acceptability of outcome measures to young people and parents; (3) investigate responses to the VRE treatment; (4) monitor whether initial benefits from treatment persisted." (p.1913)	Blind Randomised Control Trial (n = 32, Autistic children (8–14 years)—3/16 had a phobia of dogs in the treatment group) (25M/7F)	<ul style="list-style-type: none"> <li>• Social Communication Questionnaire (SCQ) Berument et al. (1999)</li> <li>• ADIS-P Silverman and Albano, (1996)</li> <li>• Vineland Adaptive Behaviour Scales (VABS) Sparrow et al. (2005)</li> <li>• Post-hoc Target behaviour ratings</li> <li>• FSSC-R-C Ollendick, (1983)</li> <li>• Children's Assessment of Participation &amp; Enjoyment (CAPE) King et al. (2007)</li> <li>• Confidence rating</li> </ul>	<b>Task:</b> A single session of Cognitive Behaviour Therapy and four session, over 2 days, with the virtual reality (blue room) or control  Customised scenes designed based on an individual's phobia. The four sessions occurred in hierarchical order from lowest severity to most intense but only if low levels of anxiety were reported. CBT and relaxation methods were used during each VR session (such as challenging thoughts)	((Only three children had a phobia of dogs—but analysed entire sample with little reference to specific cases)  In comparison to the control group, treatment groups had significantly improved on target behaviour ratings from baseline to 2 weeks ( $p = 0.021$ ) and baseline to 6 weeks after the exposure session ( $p = 0.007$ )
<b>HAI and Proxemics</b>	AR  Norouzi et al. (2019) Conference paper	"... how the presence of the AR dog affected participants' proxemics, i.e., nonverbal behavior corresponding to one's physical space in response to other entities in that space, and locomotion behavior as well as their social bond with the AR dog"	2 × 2 mixed-factorial design  [n = 21 recruited but only 15 included in the analysis (University students)] (13M/8F)	<ul style="list-style-type: none"> <li>• Co-presence questionnaire Basdogan et al. (2000)</li> <li>• Godspeed questionnaire Bartneck et al. (2009)</li> <li>• Perceived physicality questionnaire Kim et al. (2017); Lee et al. (2018)</li> <li>• Affective attraction questionnaire Herbst et al. (2003)</li> </ul>	<b>Task:</b> Five phases (Dog personalisation, play with dog, witnessing a collision with the dog, walking with/without dog)  <b>Behavioural:</b> Proxemics/locomotion (passing distance, walking speed, time looking at dog)	A sig. difference was found when alone or with a dog and speed of walking (slower when with the dog), passing distance of a person (larger when with a dog) and head rotations (more head rotations with a dog)



**TABLE 4** | Equipment and navigation methods used in VR/AR research articles. (Asterisk (\*) denotes research from the same research group).

Topic	Author	Visualisation equipment	Audio equipment	Haptics	Interaction modality
Cynophobia/ fear of dogs	Viaud-Delmon et al. (2008)*	<b>Room/CAVE/Screen:</b> single screen "300 × 225 cm <sup>2</sup> stereoscopic passive screen, corresponding to 90 × 74 degs at the viewing distance of 1.5 m, and are projected with two F2 SXGA+ Projection Design projectors. Parti-cipants wear polarized glasses." (p.3)	Sennheiser HD650 headphones	Not stated	Wireless mouse
	Taffou et al. (2012)*	<b>Room/CAVE/Screen:</b> As per Taffou et al. (2013)	Sennheiser HD650 headphones	Not stated	Wireless joystick
	Suied et al. (2013)*	<b>Room/CAVE/Screen:</b> As per Viaud-Delmon et al. (2008)	Sennheiser HD650 headphones	Not stated	3D mouse
	Taffou et al. (2013)*	<b>Room/CAVE/Screen:</b> "The immersive space was a BARCO iSpace, a four-sided, retro-projected cube with Infitec stereoscopic viewing Participants wore polarized glasses."	Sennheiser HD650 headphones	Not stated	Wireless joystick
	Hnoohom and Nateeraitaiwa (2017) Farrell et al. (2021)	<b>HMD:</b> 3D Shinecon HMD glasses used with an android smartphone <b>HMD:</b> Oculus Rift <b>Other:</b> 360 videos—Fly 360 4K camera	"Headphones" (separate to headset) Not stated	Not stated Not stated	Wireless remote control Unclear if the subject walks causing the observed scene to shift or the subject does not walk but simply watches whilst standing or sitting a 360° video as the observed scene automatically shifts/ changes
Multiple phobias	Suárez et al. (2017)	<b>HMD:</b> Oculus Rift	Not stated	Not stated	Handheld game (Xbox) controller
	Maglaya et al. (2019)	N/A (proposed HTC and/or mobile phones HMD's)	N/A	N/A	N/A
	Maskey et al. (2019)	<b>Room/CAVE/Screen:</b> 'The Blue room' "interactive computer-generated audio-visual images projected onto the walls and ceilings of a 360 degree screened room. The room was 4m <sup>3</sup> and the participant and therapist sit side by side"	Audio visual images—no further details provided	Not stated	Therapist controlled using a tablet.
HAI and Proxemics	Norouzi et al. (2019)	<b>HMD:</b> Microsoft AR Hololens <b>Other:</b> Projection of images of the environment (office) onto walls	Audio via Microsoft AR HoloLens	Not stated	Room scale walking

out), space and dimensions allocated, virtual hand movement or haptics, audio details including quality.

- Computer/mobile phone equipment: Name and model of computer/phone and technical specification (e.g., processor, graphics card, etc.).
- Dog/Animal model: Links to the sources of the model is not ideal and these may no longer work in future. Therefore, as much detail about the model is required such as: Pre-purchased, developed in house or both, physical appearance and colour availability, polygons/vertices count, justification of model choice (e.g., cost, availability, prior research, expert feedback, etc), all behaviours the model displays, justification of behaviours displayed (pre-defined when purchased, user feedback or canine behavioural expert feedback, etc). In the case where there are multiple virtual animals used a separate appendix with all the details about the model specifications and sources should be provided. Ideally, images of the model would be provided.
- Virtual environment: The virtual environment is likely to impact human perceptions and behaviour and therefore any

information about the environment used and justification of the environment is needed. Ideally, images of the virtual environment would be provided.

Alongside visual and audio feedback, haptic feedback in VR is important as it can enhance user immersion as it allows simulated physical interaction, and feedback, between a user and virtual or a combination of real and virtual objects within the virtual environment (Wang et al., 2019). For example, Carlin et al. (1997) conducted a case study of an individual with a spider phobia and found that touching a real toy spider, whilst viewing a VR spider, provoked a strong emotional response. In the present review, no articles indicated that they used haptic feedback as part of the VR setup. This could be due to the type of studies that were conducted as the majority focused on the treatment of phobia and therefore the contact with a dog may be unlikely. In contrast, the use of haptics may be of use in a dog phobia context especially for patients who are gradually exposed and become comfortable with the presence of dogs eventually coming into "contact" with the dog. The use of bespoke VR setups and varying navigation

**TABLE 5 |** Dog model breed(s) used, justification, model quality (polygons/vertices), behaviours displayed and environment(s).

Topic	Article	Breed/s	Breed used in VR study	Justification of breed choice	Model quality	Dog behaviours/vocals	Environment/s
Cynophobia/ fear of dogs	Viaud-Delmon et al. (2008)*	Built nine dog models: Alaskan Malamute, Boxer, Bull terrier Doberman, Great Dane, GSD, Miniature Pinscher Pit Bull Terrier, Staffordshire Bull Terrier	Doberman	Based on evaluation of nine breeds by ten participants who fear dogs and rated the Doberman the most negatively arousing	Not stated	Behaviours: "Several animations have been developed: running, walking, seating, jumping etc." (p.5) Vocals: Growling and Barking	Two outside environments: A street with cars; a garden with trees and a house, tables and benches One internal environment: Large dark hangar with different industrial machinery
	Taffou et al. (2012)*	Breeds not stated ("several dogs were displayed")	Not stated	Not stated	Not stated	Behaviours: "They could be unimodal and static: auditory or visual alone (a dog barking from far or a dog lying down), unimodal and dynamic (looming and receding barking or visual dog standing up when the participant approaches), audiovisual and static (visual dog lying down and growling), audiovisual dynamic (visual dog standing up and growling when the participant approaches)." (p.239) Vocals: Barking and growling	A corridor was used for behavioural approach test Training scenario and 1st environment: a garden with trees and a house, tables and benches 2nd environment: Large dark hangar with different machinery
	Suied et al. (2013)	Built eight dog models: Alaskan malamute, Boxer, Doberman German Shepherd, Great Dane, Miniature pinscher, Pit Bull Terrier, Staffordshire Bull Terrier	Doberman (three coat colours brown, black and tan 'dark' and white/grey)	As per Viaud-Delmon et al. (2008)*	Not stated	Behaviours: "Several animations of the dog model have been developed: lying, walking, seating, and jumping. The dog model could growl and bark, and the experimenter could control the dog animations with keys". (p.147) Vocals: Barking and growling	An open square with benches and a tree (with and without fog). A second garden is also connected to the first garden through a small alleyway in a residential area. The dog's location varies
	Taffou et al. (2013)	Doberman (three coat colours brown, black and tan "dark" and white/grey)	Doberman (three coat colours brown, black and tan "dark" and white/grey)	Not stated	Not stated	Behaviours: Eight different levels were shown in an increasing manner. Behaviour included was similar to that of Taffou et al. (2012) (e.g., lying down, standing up, growling and barking) and included static, moving or following Vocals: Growling and barking	As per Taffou et al. (2012)
	Hnoohom & Nateeraitaiwa (2017)	Unknown (human avatar purchased)	Rottweiler	"This paper selected the model we use that suitable and realistic with the scene" "Rottweiler is fierce" " 26 animations can apply to this work."	Not stated	Behaviours: 26 animations (not stated). The VR task consisted of three levels: 1. Dog sleeping in a living room and when participants approach it the dog sits up and starts panting 2. Standing inside a cage in the back garden. When a user gets within close proximity the dog turns and growls at the user, if the user gets closer the dog will "attack" and bark 3. The dog is standing in the back garden and behaviours are the same as level 2. However, when a user is within closer proximity the dog runs at the user and eventually leaps and attacks the user Vocals: Barking, growling, panting	Residential area—1) Living room of a house, 2) back garden in a cage and 3) outside the gate of the house  (Continued on following page)

**TABLE 5 |** (Continued) Dog model breed(s) used, justification, model quality (polygons/vertices), behaviours displayed and environment(s).

Topic	Article	Breed/s	Breed used in VR study	Justification of breed choice	Model quality	Dog behaviours/vocals	Environment/s
	Farrell et al. (2021)	Video footage of six dog breeds: <ul style="list-style-type: none"> <li>• Doberman</li> <li>• Cocker Spaniel</li> <li>• Labrador x Kelpie</li> <li>• Rottweiler x Border Collie</li> <li>• Cavoodle</li> <li>• Japanese Spitz</li> </ul>	All six breeds used in VR video Post VR assessment with a real dog—dogs varied and no breeds were stated	<i>"Each dog was selected based on providing a variation of breeds and sizes to maximize variability."</i>	4K 360° video viewed in a VR HMD	Behaviours: There were ten levels including: "1 Dog and assistant walks into and sits on the opposite side of the room (on leash); 2 Subject moves closer to dog (on leash); 3 Subject moves closer to dog (on leash); 4 Subject moves directly next to dog (on leash); 5 Subject back to original side of room, assistant and dog standing up walking 1m forward (on leash); 6 Assistant and dog standing up walking 1m forward from previous position (on leash); 7 Assistant and dog standing up walking 1m forward from previous position (on leash); 8 Dog walking side to side and around camera (on leash); 9 Dog walking/ running towards subject (off leash and assistant in room); 10 Dog without assistant in room and no leash" (p7.) Vocals: Not stated	"A large room" was used for the VR video treatment and post treatment. (limited information provided)
Multiple phobias	Suárez et al. (2017)	German Shepherd	German Shepherd	Pre-defined behaviour on purchase	<i>"Each of these models is really well made"</i>	Behaviours: "walk, run and sit" Vocals: Not stated	"3D House model with three floors and furniture"
	Maglaya et al. (2019)	Not stated	Not stated	Not stated	Not stated	Behaviours: Minimal detail [ <i>"The Patient will be situated inside a house. Lower levels of the experience will involve sounds coming from a dog. The next level will be a shadow of the dog and gradually revealing a dog outside the window. The next level will be a dog on a leash slowly getting closer to the patient until the patient can touch the dog."</i> (p.140)]	<i>"The Patient will be situated inside a house."</i>
	Maskey et al. (2019)	Not stated	Not stated	Not stated	Not stated	Behaviours: Minimal detail ( <i>"Scenes are individualised, incorporating an exposure hierarchy related to the feared stimulus. For example, for dog phobia, adaptations include the dog's size, whether on or off a lead, barking, and proximity to the participant."</i> ) (p.1916) Vocals: Barking	<i>"Scenes are individualised, incorporating an exposure hierarchy related to the feared stimulus. For example, for dog phobia, adaptations include the dog's size, whether on or off a lead, barking and proximity to the participant."</i> (p.1916)
HAI and proxemics	Norouzi et al. (2019)	Purchased (active link to external site)	Beagle (with four different coat textures)		808 tris [via link to model (p.3)]	Behaviours: 42 pre-defined animations ( <i>"including included eating, drinking, digging, walking, barking, sitting, resting, scratching, sniffing, and falling over"</i> ) (p.160) Vocals: Panting, barking and sniffing	<i>"a 3.89mx3.89m immersive CAVE-like environment with four projection walls and two doors facing each other. Regular office like images were projected onto the walls to make the participants feel like they were in an ordinary office room. We also prepared a 6.4m by 2.14m walkway platform outside the interaction room, which we used to measure the participants' walking behaviors with/ without the dog"</i> (p.161)

methods (e.g., mouse/joystick) by individual laboratories may have also played a role in the lack of haptic feedback used as separate development may have been needed. Having said this, the use of realistic haptic feedback in VR is complex and commercial VR controllers are limited to various basic forms of vibrations (Wang et al., 2019; Yin et al., 2021). Further research exploring the use of basic and more complex forms of haptic feedback (see review by Yin et al. (2021) for the current and future use of haptics in AR and VR) in human-dog interaction studies in AR/VR would be beneficial, especially in dog phobia and educational research.

In the present review only one article used AR. More research is needed on the use of AR dog models as it provides increased ecological validity compared to VR and interaction with a users own hands rather than virtual hands (Suso-ribera et al., 2019).

## Research Studies

The majority of articles focused on the assessment and treatment of humans with a fear or phobia of dogs or animal related phobias. For example, Farrell et al. (2021) found that the majority of participants (75%) were deemed to have recovered 1 month after a one-session treatment, but the sample was small ( $n = 8$ ). This technology could be beneficial in future clinical real-world applications. Recent hospital data indicates that NHS waiting times in England are an important public concern (The Kings Fund, 2021). There has also been a significant increase in demand for mental health services which has been exacerbated by the COVID-19 Pandemic (NHS Providers, 2021). In addition, the rate of hospital attendance due to dog bites has reported to have increased during COVID-19 lockdowns, likely due to the increased contact between humans and dogs (Dixon and Mistry, 2020; Tulloch et al., 2021b). This could result in an increased rate of dog bite victims seeking mental health advice and treatment (such as for PTSD or ASD). However, mental health interventions such as exposure therapy is deemed a non-urgent treatment. Therefore, further research into the role of AR and VR technology which could assist mental health practitioners or even replace the involvement by professionals is needed.

Exposure therapy could be an opportune moment for the education of individuals about appropriate and inappropriate behaviour in the presence of dogs and general dog behaviour. Yet, only a single paper mentioned, although briefly, that the researchers incorporated education about dog behaviour and safe interactions with a real dog (Farrell et al., 2021; p.7). This highlights the potential for future research using VR and AR dog models as a form of educational intervention, either stand alone or alongside phobia treatment, for both children and adults, regarding appropriate behaviour around dogs and recognition of specific dog behavioral signals. Further exploration is needed into the impact that experiences with AR and VR dog models and associated educational applications have on the potential for participant behaviour change. As previously highlighted by Schwebel et al. (2012) dog bite prevention education in the form of online software may increase knowledge but does not result in behaviour change.

Often VR dog models are developed for an individual or multiple studies by the same organisation/research group and therefore there is little systematic re-use of dog models. Having different dog simulations makes comparisons difficult as each simulation may have different effects on human users, depending on how accurate the models appearance and behaviour is. Similar issues have previously been highlighted in research involving virtual human avatars (Mountford et al., 2016). Further, little reference to the quality of the model (e.g., high or low polygons) was provided. Judging the quality of dog models is important due to the potential impact it has on a user's behaviour towards and interpretation of the dog. Previous research has highlighted that the impact of model quality and design (i.e., anthropomorphic features, naturalness, stylisation) could relate to the perceived realism of virtual animals (Schwind et al., 2018). For example, Schwind et al. (2018) note that if a virtual animals appearance deviates from its natural appearance (e.g., human facial expressions), or movement, then this can result in negative perceptions (e.g., eerie sensation/uncanny valley) of the virtual animals and may have the potential to affect interactions with them. In contrast one study, used a VR HMD (Oculus Rift) to view 360 degree videos of real dogs with positive results (Farrell et al., 2021). Initially this method appears to overcome issues associated with the need to design accurate and realistic models. However, this format of VR has several practical limitations. For example, firstly, interactions with dogs in the video is not possible; secondly, initial video footage is required with various dog breeds, behaviours, space and permission to film the footage is required. Thirdly, additional ethical approval is needed for both the use of animals, especially where a dog may be display aggressive behaviours, and human participants (Swobodzinski et al., 2021).

## Dog Breed

Several articles chose specific breeds such as Rottweilers or Dobermans (Viaud-Delmon, 2008; Hnoohom and Nateeraraitaiwa, 2017). In some cases, breed choice was justified, for example, Viaud-Delmon (2008) conducted the screening of nine different breeds, and based on ten participants, found that the Doberman was the animated dog model which provoked the most negative emotional response. However, the latter study did not state if participants had any previous experience with dogs or were involved with a dog related incident such as a bite. Further research would be useful to ascertain the difference between individual perception based on limited or no experience of dogs and those who are phobic of specific breeds due to a dog related incident.

Furthermore, other research does not appear to justify the choice of breed or chooses a breed based on likely biased perceptions of the breed; for example, Hnoohom and Nateeraraitaiwa (2017) used a virtual reality dog model based on a Rottweiler breed and refers to the dog as a "fierce dog". Similarly, an online company advertising the treatment for the fear of dogs through VR also states, "One of the most commonly feared dogs, Rottweiler, often considered dangerous" (Psious, 2018). Similar inflammatory language (e.g. "ferocious" and "vicious") has been previously reported for Rottweilers and German Shepherds in medical literature (see Arluke et al., 2018, p.216).

Choice of specific breeds could have been influenced by external factors such as the news media which often focus on specific breeds (Kikuchi and Oxley, 2017) or breeds, such as Rottweilers, German shepherds and Dobermans, frequently used as guard and police dogs (Podberscek, 1994; Meade, 2006). A recent survey of veterinarians in the United States regarded the Rottweiler and German Shepherd as breeds which poses a high risk of biting and evoke a negative emotional response if an unfamiliar adult dog, which was off the lead, ran up to them (Kogan et al., 2019). Although it is likely that some breeds may be perceived as more aggressive or fearful than others, it is important to highlight that all dogs have the potential to bite and can be due to multiple factors such as management, health status, genetics, and environment (including human and dog behaviour) (Haug, 2008). The role of dog model physical characteristics and the impact it has on human perception and behaviour is an area that requires further research, for example the effects of skull (brachycephalic, mesocephalic and dolichocephalic) and ear shape, tail length, coat colour and type, size (toy, small, large, giant) and weight (underweight or overweight).

## Coat Colour

The coat colour of the dogs was briefly discussed. Suied et al. (2013) found that participants were more fearful of a dark coloured dog in comparison to a white or brown. However, given the same Doberman model was used, the reaction of participants could have been in relation to the most realistic dog model in terms of both breed and natural colour, as Dobermans are stereotypically known and associated in roles and the media with black coats and less often brown or not at all with white coats. Further research would be useful into the impact that coat colour has on human behaviour and participants perceptions; especially as black dog syndrome (also known as big black dog syndrome) appears to be frequently mentioned online despite there being little evidence to support this phenomenon (Woodward et al., 2012; Sinski et al., 2016). In previous research, breed specific differences and size have been found to be more influential factors than the coat colour of dogs (Woodward et al., 2012; Sinski et al., 2016). From a research perspective, VR is a useful tool in this respect as size and colour can be controlled and changed with relative ease, whereas multiple similar-looking dogs would be required in real life scenarios to test these variables.

## Dog Behaviours

The dog models used in this review appeared to display generic behaviour with limited evidence of behaviours being based on canine behavioural science research or expert feedback. It was evident that behaviours were frequently predefined based on models that were purchased. This could be due to the type of research that the dog models were being used for (i.e., dog phobias) and therefore it was perceived that a dog model which displays basic behaviours such as walking, sitting, barking, jumping were required. Alternatively, models that can be purchased with predefined behaviours can be preferable as less time is needed for development. However, accurate behaviour representation is important to consider, especially in the case of dog phobic participants. The display of subtle (e.g., growling,

barking) and more intense (e.g., running towards, lunging or attacking (Hnoohom and Nateeraitaiwa, 2017)) behaviours towards participants is likely to be required for realistic treatment but also may cause significant stress and needs careful consideration in this context.

Realistic behaviours can be included in a form of exposure therapy and range from relaxed, play to fear and agonistic behaviours. It is important to note that dog behaviour can be complex and could be easily misinterpreted by an untrained individual. For example, appeasement signals (also known as calming signals) may include behaviours such as lip licking, yawning, and paw raises, indicating stress and discomfort which are often misinterpreted (Shepherd, 2009) and were not included in the reviewed articles. Similarly, theories about dog behaviours and their meaning can vary such as in the case of dominance of dogs towards humans (Westgarth, 2016). This highlights the importance of collaboration between animal behaviour experts and VR/AR developers. Often this type of collaboration appears to be lacking presumably due to the need for large amount of animation and technical development of models or the reliance on predefined models.

Finally, the importance of messaging also needs consideration, even if hypothetical, within the virtual environment especially regarding the treatment and management of animals. For example, Hnoohom and Nateeraitaiwa (2017) display a virtual dog within a cage which, if in reality, would be considered a serious welfare concern in many countries.

In conclusion, this review highlights the current limited use of dog models in VR and AR. The small number of reviewed articles generally were also limited by small sample sizes and the results need to be interpreted with caution. This review also only included English articles. Despite this there was some evidence to indicate that the use of VR to treat dog phobias is effective and holds much potential, especially including the assessment of participants physiological parameters (heart rate, skin conductance, eye tracking, etc). Of the studies found, there is a lack of emphasis placed on the dog model's behaviour, breed and quality. Future developments and research need to consider appearance (e.g., breed and unbiased basis for this), canine behaviour (based on up-to-date evidence-based research and canine behavioural expert review) and quality of dog models. We also recommend that the detail of the dog model is reported including the sources or development of the model, quality (i.e., polygons/tris/vertices), and behaviours displayed. Future collaboration between canine behavioural experts and VR and AR developers would be beneficial for an accurate and realistic representation of dogs in virtual reality.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

## AUTHOR CONTRIBUTIONS

JO, CW, GM discussed and conceived the research idea. JO, KS collected and identified relevant articles from the databases. JO



reviewed all articles and wrote the first draft of the manuscript. CW, GM, KS provided feedback, discussion and comments on drafts of the manuscript. All authors discussed and contributed to the manuscript.

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