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Now I Wanna Be a Dog: Exploring the Impact of Audio and Tactile Feedback on Animal Embodiment

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Figure 1: (1) Dog avatar being brushed by the virtual character and (2) the experimenter brushing the participant's back for the tactile condition. (3) View of the virtual shelter and (4) virtual character trimming the dog avatar's fur using scissors.

ABSTRACT

Embodying a virtual creature or animal in Virtual Reality (VR) is becoming common, and can have numerous beneficial impacts. For instance, it can help actors improve their performance of a computer-generated creature, or it can endow the user with empathy towards threatened animal species. However, users must feel a sense of embodiment towards their virtual representation, commonly achieved by providing congruent sensory feedback. Providing effective visuo-motor feedback in dysmorphic bodies can be challenging due to human-animal morphology differences. Thus, the purpose of this study was to experiment with the inclusion of audio and audio-tactile feedback to begin unveiling their influence towards animal avatar embodiment. Two experiments were conducted to examine the effects of different sensory feedback on participants' embodiment in a dog avatar in an Immersive Virtual Environment (IVE). The first experiment ($n=24$) included audio, tactile, audio-tactile, and baseline conditions. The second experiment ($n=34$) involved audio and baseline conditions only.

Keywords: Virtual Reality, Embodiment, Audio Feedback, Tactile Feedback, Perception.

Index Terms: Human-centered computing—Interaction design—Epirical studies in interaction design; Human-centered computing—Interaction paradigms—Virtual reality

1 INTRODUCTION

As Virtual Reality (VR) becomes more commonplace, users are seeking out unique experiences where they can embody avatars that go beyond the limit of their real bodies, such as creatures and animals. Additionally in the film industry, on-set pre-visualization of computer-generated content in VR is becoming standard practice and allowing actors to embody creatures and animals can improve their performance of a computer-generated creature [20]. In more serious applications such as climate-change visualizations, it can endow the user with empathy towards threatened animal species [1].

However, in order to provide convincing experiences, it is necessary that actors feel a Sense of Embodiment (SoE) towards their virtual representation, i.e., the feeling of being inside, having, and controlling their virtual body [21]. This is commonly achieved by providing congruent sensory information such as visuo-motor (users moving and watching their virtual body moving congruently), and visuo-tactile feedback (an external effector providing tactile stimuli on the user's real body, synchronised with visual stimuli on the virtual body). In particular, these methods were found to influence the three subcomponents of the SoE as defined by Kilteni et al. [21] (the senses of self-location, agency and ownership).

While these studies mainly focused on anthropomorphic avatars, a few works explored how these methods could be beneficial to experience a SoE towards dysmorphic avatars (i.e., virtual body types that differ from the users' real bodies in terms of body morphology and structure), such as creatures or animals [1, 23, 35]. However, in the case of highly dysmorphic bodies, providing convincing visuo-motor feedback can be challenging due to discrepancies between the physical and virtual bodies. As for visuo-tactile feedback, it has the limitation of requiring the involvement of external stimulation (e.g., delivered by either an experimenter or a robotic effector [19]). Therefore, it is important to explore other alternatives to provide a fulfilling SoE towards dysmorphic avatars in VR. Among them, the use of audio feedback is promising as it is an essential component in the perception of the environment and one's location and interaction within it. Yet, its contribution towards the perception of one's own virtual body remains largely unexplored.

Outside the scope of VR, previous works investigated the capacity of audio feedback to alter the mental representation of one's physical body (e.g., its size, weight, and material properties) and also to enhance the body-related emotional state [40, 47, 49]. The topic was then tackled in an Immersive Virtual Environment (IVE) to study the impact of audio feedback on the SoE towards a dysmorphic avatar (a bird) [42], and in a non IVE to measure its influence over the SoE towards anthropomorphic virtual bodies [29]. While these works found little to no effect of audio feedback on the SoE, it is unclear whether it is due to a small sample size (12 participants) and non-immersive setup [29], or because of the nature of the audio feedback used (sounds that result from movement of the body, such as the sound of wind when the character's wings flapped [42] or when hands clapped [29]). Another study in IVE found a positive influence of audio combined with tactile feedback for altering the perceived material of an embodied avatar (transforming the avatar skin from human to stone) without breaking the SoE [9]. However, neither this

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study nor the study from Lugrin et al. [29] explored the influence of audio feedback alone as an isolated factor without tactile stimulation. In addition, their study focused on the perception of one's virtual hand and it is unclear whether such findings could extend to the perception of a whole altered avatar, and in particular to the SoE towards a full dysmorphic body, such as an animal. Considering the limitations previously mentioned, it is still unclear whether audio feedback alone, without visuo-motor or visuo-tactile feedback, can contribute to eliciting a SoE towards full-body dysmorphic avatars. While visuo-motor feedback is commonly provided in embodiment applications, it can be challenging to arrange for dysmorphic avatars with strong structural and morphological differences from the users' bodies. In addition, we believe it is important to isolate audio feedback in a controlled setup in order to fully appreciate its contribution to the SoE elicitation. Also, because audio-tactile stimulation only considered punctual sounds in previous work [9], continuous sounds remain to be explored in this context.

For this reason, we aim to study in this paper the influence of continuous audio feedback and its combination with tactile feedback on the SoE towards a dysmorphic avatar. In particular, we decided to focus on an animal avatar (a dog) for two reasons. First, a dog has a structural morphology that differs from humans, which makes it challenging to feel embodied in and to assimilate to one's self this change of body space. Second, dogs have fur which, rendered as individual hairs, is a characteristic that is very difficult to achieve accurately in real-time and in particular in VR, as it requires high computational resources. Therefore, it is a feature that is usually unavailable in VR currently or renders poorly, which reinvigorates the need to explore other methods to enhance the feeling of having a fur in VR. Consequently, two research questions were highlighted:

RQ1 Can continuous audio feedback combined with tactile feedback increase the SoE towards a dog avatar?

RQ2 Can continuous audio feedback alone increase the SoE towards a dog avatar?

To explore these questions, we conducted two experiments in which participants were embodied in a dog avatar and experienced different types of sensory feedback to assess the potential of audio and audio-tactile feedback in eliciting a SoE towards an animal avatar. In the first experiment, participants ($n=24$) were immersed in an IVE and could watch themselves in a mirror being brushed by a human virtual character under four conditions: visual with audio feedback, visual with tactile feedback, visual with audio-tactile feedback, and a visual only control condition. The second experiment sought to explore the audio feedback condition further. Participants ($n=34$) could see their virtual selves getting their hair trimmed while being immersed in the same IVE and embodied in the same dog as in experiment one. This experiment involved visual with audio feedback and a visual-only control condition. For each of the experiments' conditions, participants answered a questionnaire to rate their SoE towards the dog as well as other perceptive items (e.g., subjective warmth and threat perception). The two experiments and their conditions can be observed in the accompanying video submitted with this paper. Our results extend earlier research findings by revealing that audio-only feedback has minimal effect on the SoE although some tendencies were observed. We also reveal the impact of individual differences (gender and empathy trait) on several items related to the SoE.

Overall, this study was motivated by the lack of knowledge on how to improve the SoE towards dysmorphic avatars such as animals, which is primordial for actors in VR or effective empathy suggestibility experiences. Therefore, this study aimed to investigate the potential of audio and audio-tactile feedback for providing a SoE towards non-humanoid avatars such as creatures and animals.

Results were more promising regarding the use of tactile feedback than audio feedback for altering the perception of a body feature

(e.g., the sense of owning a fur) as well as eliciting a SoE over a dog avatar whose morphology differs from human, paving the way for future research to further explore multi-modal feedback in providing a SoE towards dysmorphic avatars.

2 RELATED WORK

The power of immersive experiences relies on tricking users' brains into believing they are in a virtual environment, creating a physical and psychological connection towards it [44] and experiencing different illusions. The experience of possessing, commanding, and inhabiting a virtual body is referred to as the SoE. This illusion results from when users feel that the avatar's physical characteristics belong to their biological bodies [21]. The SoE is based upon three subcomponents: the sense of self-location (self occupies a specific volume of space), the sense of agency (having global motor control over the body), and the sense of body ownership (feeling of self-attribution towards a body) [6, 21]. These subcomponents derive, in turn, from a series of factors which correlate with each other [14], such as the avatar's appearance (shape, characteristics, and realism [26, 30]), the point of view (PoV) from which users interact and perceive the IVE [30, 45] and the level of control over the virtual avatar [39, 45]. Interestingly, the SoE has been demonstrated to exist even when the body features of the avatar, such as gender, age, anthropomorphism and race, differ from those of our actual body; as well as by adding extra limbs or even by giving the user's virtual avatar a tail-like bodily extension [2, 27, 28, 46]. In this vein, a more limited amount of research investigated the SoE towards animal avatars and their potential beneficial outcomes.

2.1 Animal Embodiment

Given the endless possibilities of VR for creating IVEs, we might desire to embody non-humanoid avatars in different contexts. For instance, we could embody a fantastical creature to improve our acting performance [20], experience the environment through the eyes of a particular species for educational purposes or to raise awareness [1, 41], or simply for entertainment purposes. Similar to humanoid embodiment, the point of view and control of animal avatars are essential to evoke a SoE [22, 23]. Yet animal embodiment comes with challenges that must be considered to elicit an effective SoE. The morphological diversity of animals is the first thing to take into consideration, as animals differ significantly in shape and form. Therefore, there may be significant differences between our morphology and that of the animal we want to embody. Krehov et al. [23] determined three aspects essential to successfully eliciting an SoE: skeleton, posture, and shape and investigated embodiment towards animals that varied in one of these three aspects with respect to a humanoid avatar: a bat (shape), a tiger (posture), and a spider (skeleton). This allowed them to assess various control modes and mapping approaches and gain diverse insights into animal embodiment. Their findings suggest that despite morphological differences, a SoE towards virtual animals is feasible. They also found that first-person perspective generally performs better than other points of view, and positions similar to those of humans are preferable because animal poses might be physically taxing for participants.

Providing rich sensory feedback was also shown to improve embodiment towards virtual animals [1, 41]. Ahn et al. [1] conducted a series of experiments in which participants were exposed to visual, haptic and sound feedback while embodied in a shorthorn cow and a coral on a rocky reef. Their results suggest that increased feelings of embodiment, presence and a sense of connection between the self and nature were experienced as a result of including rich multi-sensory feedback. Likewise, Pimentel et al. [35] investigated the impact of visuo-motor and visuo-tactile stimulation by immersing participants in the body of a loggerhead sea turtle and allowing them to control the virtual avatar using their head and hands as well as providing them with synchronous haptic stimulation to their spine.

Their findings not only show that body transfer via non-humanoid avatars is feasible but also suggest that animal embodiment could be used for biodiversity conservation as users perceived their virtual bodies as a conduit for the victims' lived experiences.

Indeed, animal embodiment in IVEs has been used to investigate its influence on empathy, the ability to share feelings and establish an emotional connection with others, and to increase the awareness of animal abuse, wildlife and the environment by placing participants in the position of animals and experiencing distressful events [1,35,41]. Sierra Rativa et al. [41] developed an IVE to investigate if users' empathy, immersion, and perceived pain changed when a virtual animal was embodied. In their experiment, participants experienced a distressful event with three avatars: a realistic beaver, a robotic beaver, and an amorphous body character. They demonstrated that the virtual avatar's appearance substantially affected immersion and pain perception, but not situational empathy or embodiment.

Moreover, Oyanagi et al. have investigated the Proteus effect on a bird avatar [31, 32]. The Proteus effect, similar to self-illusion, postulates that a user's behaviour, attitude, and mental state are affected by the avatar's appearance [51]. Therefore, by embodying participants into a bird avatar, researchers found that due to birds' inherent ability to fly, a bird avatar can significantly improve the psychological experience of flying [31]. In addition, they also reported that inducing ownership over a bird avatar in a flying experience reduces participants' fear of heights and falling [32]. Similarly, Li et al. [25] conducted an experiment in which participants played the role of a cat (a non-human role) to interact with a virtual world to elicit and measure a sense of self-illusion (perceiving ourselves as the role played in the IVE). They discovered that a user's high level of self-illusion generally contributes to a greater connection to the virtual role and results in more coherent responses within the IVE.

Overall, the SoE over animal avatars has been explored with different species (tiger, bat, spider, scorpion, rhino, bird, beaver, turtle, cat, shorthorn cow, and coral reef) and goals: from identifying the contribution of visuo-motor and visuo-tactile feedback on the SoE to exploring potential outcomes as empathy, conservation of species, pain perception, or illusions like the Proteus effect. However, the quantity of studies remains limited, and to the best of our knowledge, providing efficient and coherent sensory feedback while embodying an animal with morphological mismatch with the user and giving a sense of owning its specific material features (e.g., fur) remains challenging. Among other sensory alternatives, audio feedback remains underrepresented in the context of virtual embodiment.

2.2 Audio and Tactile Feedback and Embodiment

Being immersed in a real or virtual environment requires spatial awareness of our surroundings and the location of objects with respect to oneself. Sound localisation enables us to recognise the presence, distribution, and interaction of sound sources as well as information regarding the environment [24]. It refers to the collection of perceptual properties of audio signals that allow the auditory system to determine the position and distance of a sound source from the listener through the combination of inter-aural time differences (ITD), inter-aural level differences (ILD), amplitude, and mono-aural cues [3, 8]. As VR is predominantly a visual medium, the environment's acoustic reproduction must, however, be congruent with the visual feedback of the space [17]. Sound auralization refers to creating a realistic acoustic response of an environment using phenomena such as early reflections, reverberation, and occlusion [17]; which, combined with the radiation patterns and spatial locations of audio sources in space, allow rendering a sonic environment to provide listeners with a greater sense of immersion in an IVE [16].

Our body connects us with the world around us, and it is through the senses that we perceive and interact with our surroundings, whether physical or virtual [9, 49]. Audio feedback plays a significant role in how we perceive ourselves, our environment, and

how we relate to it. Since we interact with the environment through our bodies, which itself makes sounds like breathing and coughing, these interactions almost always result in sound. We can refer to the sound produced and related to our body as a sonic self-avatar [49]. The term not only refers to the sounds made by our body, but it also encompasses the information about one's body, such as its dimensions, emotional state and actions.

The mental representation of one's body is not fixed, and the brain continuously integrates sensory information from multiple sources [9,40,48]. Research on audio feedback has shown that the perception of our body size and weight can be changed by altering the sounds made by our body in synchrony with our movements [47]. Multi-sensory feedback, such as audio-tactile feedback, has also been found to change our body perception. Taradura-Jiménez et al. [48] found that when participants received feedback about a ball being dropped from a greater distance, they perceived their legs and entire body as longer than usual. These works were however not conducted in VR.

Senna et al. [40] also examined whether the perception of body's material properties could be altered through audio-tactile stimuli by hitting participants' hands and gradually substituting the sound of a hammer against the skin for that of a hammer against a stone. They showed that when the audio-tactile feedback was synchronous, and the impact of the sounds provided clear and unambiguous cues about the object's material, participants' perception of the material properties of their hands was altered. Based on this experiment, Buetler et al. [9] studied the effects of multi-sensory feedback on the motor brain networks and control in VR by altering the physical characteristics of an embodied avatar. While immersed in VR, participants observed the visual appearance of their avatar arm changing gradually from human skin to stone. In addition to the visual transformation, participants received audio-tactile feedback with a hammer touching their actual arm and audio cues that transitioned from skin to stone in time with the visual feedback. They found that when the ownership illusion of a stone happened, participants experienced perceived their arm as colder, heavier and stiffer.

Some studies have examined the influence of self-produced audio feedback on the SoE in VR. Sikström et al. [42] conducted an experiment exploring the impact of audio stimuli on the sense of ownership of virtual wings. They examined how self-produced sounds affect participants' perception of control and ownership over virtual wings in an IVE using a variety of audio feedback, including sounds of wind, footsteps and wings flapping. However, participants perceived little to no difference between conditions: no sound, body-only sounds, body and wings sound, and body sounds and asynchronous wings sound. Similarly, Lurgin et al. [29] investigated how audio feedback affected the SoE in non-immersive mixed reality (MR) environments. Their method entailed a mixed-reality game that considered two factors: audio and no audio feedback, human and non-human (robot) avatars. According to questionnaire-based and control-based results, audio feedback appeared not to affect the SoE, suggesting that virtual body sound cues are not necessarily required for the SoE. However, this study had a small participant sample size (12 participants) which raises the margin of error and limits the experiments' findings.

In summary, the impact of audio and audio-tactile feedback on the SoE over dysmorphic virtual bodies has been partially tackled in previous research. However, in these studies audio feedback was either associated with visuo-motor or visuo-tactile feedback, making it hard to really understand the contribution of audio feedback alone on the SoE. While one experiment isolated the audio feedback, the very small participant sample size limits the strength of the experiment's findings but also, their experiment was not conducted in an IVE and the avatars used remained anthropomorphic. Therefore, there is currently a lack of knowledge regarding the contribution of audio feedback alone and its combination with tactile feedback on

the SoE towards dysmorphic avatars.

To further illustrate this section, two tables can be found in supplementary material summarizing the studies presented here-above.

3 EXPERIMENTS

This paper aimed to explore the potential of audio and audio-tactile feedback for providing a SoE towards a dysmorphic avatar in VR, and in particular a dog. To that aim, we conducted two experiments in which participants were immersed in a dog shelter environment, embodying in first-person a virtual dog whose head movements were mapped from the participants' head's orientation, and experiencing different types of sensory information and stimuli. A dog-shelter environment was selected as an ecologically valid location, where we also had the possibility of inducing empathy towards dogs (see Figure 1, third).

3.1 Experiment 1

In this experiment, a virtual human character was animated to brush the dog avatar while participants received synchronously either audio, tactile (from the experimenter), audio-tactile or no additional feedback (as a control condition). The virtual character's action was chosen to facilitate the perception of spatial audio features where the sound changed in both position and direction and to provide continuous tactile feedback to participants. The experiment was conducted using a within-subjects design to reduce errors related to individual differences across conditions. The order between each stimulation was counterbalanced between participants to account for potential ordering effects; therefore, variables were presented in all possible permutations. Two independent variables were considered, whose levels depended on the different feedback provided to participants. *Tactile* feedback could either be Tactile (VT): the experimenter brushed the back and arms of the participant with a real brush synchronously with the virtual brush movement, or without Tactile (WVT): no tactile feedback provided. *Audio* feedback could either be Audio (VA): spatialized pre-recorded brush sounds were played synchronously with the virtual brush movement; or without Audio feedback (WVA). When VT and VA were combined, the participant was exposed to the tactile and audio stimuli synchronously with the virtual brush movement. When WVT and WVA were combined, there was no additional feedback, only visual feedback of the brushing.

We believe that exposing participants to specific audio feedback, such as fur brushing sounds, will increase their sense of owning a virtual fur, and by extension their SoE towards the virtual dog, especially, when paired with additional stimuli such as tactile feedback. Based on previous work showing that audio-tactile feedback towards a virtual marble arm could induce a sense of feeling cold [40], we also expected audio feedback to have an impact on participants feeling of warmth. Moreover, considering that embodying animals was shown to influence nature conservation behaviors [35], we assumed increased SoE towards the dog avatar would lead to higher empathy towards dogs in shelters. More precisely, our main hypotheses are:

- H1** VA will provide a higher SoE compared to WVA.
- H2** The combination of VA and VT will have a more significant effect on the SoE than all other conditions.

3.1.1 Sensory feedback

In the virtual scene, an animated human character brushed the dog avatar (see Figure 1, first). The overall brushing animation consisted of four stages, focused on different parts of the dog's body: the back's center, the back's right side, the back's left side and the left forelimb. These animations were designed to loop seamlessly to their recurrence and sequencing. Every separate animation was played twice in a sequence that looped at least two times, providing over 1:40 minutes of brushing. In synchrony with this visual information, audio, tactile and audio-tactile feedback were provided.

Audio feedback The audio implementation was mainly designed to induce a SoE, but we additionally included additional audio sources to increase the plausibility of the scene. The brushing sounds (played in synchrony with the virtual character's animation) were newly created dry monophonic recordings of a deer skin rug being brushed. Recording a live dog was not feasible as we needed to capture noise-free and consistent recordings of continuous brushing audio. Therefore, we examined different static pieces, including rugs and skins of various materials and lengths, to identify the best alternative. A deer skin was chosen to obtain high-quality and realistic audio samples of fur, given the similarity between the hair length compared to the dog avatar. Furthermore, to ensure synchrony between the audio and visual feedback, the audio clips were trimmed to the length of the animation's fur brush strokes.

Additionally, as ambient noises can enhance the immersive qualities of VR [36], we created an acoustic scene of contextual sounds in the virtual room to enhance plausibility, including air vent humming, dripping water from a sink, panting and whining from the other virtual dogs, soft breathing of the virtual character. These ambient noises were present in all experimental conditions at a level that would not disrupt the audio stimuli to preserve a similar level of immersion between conditions. Finally, we created a virtual acoustic response matching the room's characteristics to enhance the acoustic environment's realism and provide additional sound localization cues. We used the Audio Propagation feature of the spatializer to select appropriate materials for the surfaces of the virtual room, such as ceramic tile for the walls and floor and acoustic tile for the roof. Additionally, we enabled the early reflections and reverberation settings in the spatializer's reflection engine.

Tactile and audio-tactile feedback While participants were immersed in the virtual scene, the experimenter provided tactile feedback by physically brushing their backs and arms with a plastic bristle hair-brush (see Figure 1, second). The feedback was synchronous with the virtual human's animations and was applied to: the back's center, the back's right side, the back's left side and the left arm, matching the locations of the dog. Participants were asked to wear a thin long-sleeve top in order to maintain the constancy of the brushing feedback between their backs and arms.

In order to maintain a more straightforward experiment setting, we did not employ real-time motion capture of the experimenter to animate the virtual human and synchronise the tactile feedback. Instead, to ensure the synchrony between the physical and virtual brushing, the experimenter monitored a progress bar displaying the duration of when the brush came into touch with the dog's body in each individual animation. Following the progress bar and the animation itself allowed the experimenter to time the brushing motion and speed accurately.

3.1.2 Experimental Setup

The experiments were designed to run on a tethered Oculus Quest 2 system, comprised of the HMD (Head-Mounted Display) and two hand-held controllers. The HMD was connected using Meta Link Cable to a VR-ready PC computer. A pair of Beyerdynamic DT-770 Pro 80 Ohm headphones were connected directly to the computer's audio output for audio playback.

Virtual dog In this study, we chose a dog as the animal to be embodied by participants as it differs from humans in its natural posture while maintaining a similar skeleton and number of limbs [23], but also considering the cultural relationship and familiarity to the animal. Moreover, a first-person point of view was employed to embody the dog since research has shown that it increases the sense of virtual body ownership and sense of self-location [18]. The dog's body was fixed, and participants only controlled the motion of the virtual dog's head with the HMD. Since we were mainly interested in studying audio feedback alone, we restricted visuo-motor feed-

back. Giving participants control of the dog's head was necessary to ensure an efficient first-person point of view towards the dog.

To obtain natural and realistic head movement while maintaining the fixed position of the dog's body, we developed an Inverse Kinematics (IK) method to control the head and neck bones of the dog's rig with the HMD. The system only used the HMD's rotation and applied a multi-rotation constraint to the head and the neck's three bones to account for the differences in translation between the HMD and the avatar head.

Virtual Environment The IVE was built in Unity Game Engine (version 2021.3.2f), and scripts were written in C#. In addition, BiomotionLab Toolkit for Unity Experiments [4] was used to efficiently run the experiment and log all of the participants' answers. The virtual room and 3D models were designed in Unity or obtained from CG Trader and TurboSquid. The virtual character was taken from the Microsoft Rocketbox collection, while the dog model was sourced from Unity's asset store.

The sound design and audio spatialization in the virtual environment were implemented using the Oculus Audio Spatializer (version 32.0.0). We employed the Audio Propagation feature of the spatializer for real-time reverb and occlusion modelling from the scene geometry. All the custom audio samples were recorded in an acoustically treated room using an AKG C414 microphone and a Chandler Limited TG2 Dual Mono Mic Preamp. In addition, several sound effects were taken from the Sonnis GameAudioGDC library.

3.1.3 Participants

To determine the sample size for the experiment, we conducted an a priori power analysis using G*Power [12, 13]. To accommodate for a medium effect size, we chose an effect size of $d = 0.25$, an alpha error probability of 0.05, and a power of 0.8. As we planned to run a within-group repeated measures ANOVA, we set the number of groups to 1 and the number of measurements to 4 to account for the conditions in the experiment. The correlation between repeated measurements and nonsphericity correction was set at their default value. Based on the power analysis, 24 participants took part in the experiment over a period of two weeks. Participants were recruited through university mailing lists.

Prior to the experiment, participants read and signed an informed consent form and completed a demographic questionnaire about age (between the ages of 22 and 53, mean/s.d. age: 33.5 ± 7.7), gender (13 males, 10 females, 1 prefer not to say), ethnicity (5 Asian or Pacific Islanders, 2 Hispanic or Latino, 17 White Caucasians), VR experience (5 experts, 2 moderate users, 9 sporadic users and 8 never used) and video games experience (4 experts, 7 moderate users, 10 sporadic users and 3 never used). The experiment complied with the guidelines established by the university's ethics committee and the Helsinki Declaration. and had prior approval from the board.

3.1.4 Procedure

The experiment was divided into two parts: a screening test to determine whether the participant was, to some extent, compatible with the generic Head-Related Transfer Function (HRTF) used for sound spatialization, and the main experiment, in which participants were immersed in VR and exposed to different sensory stimuli.

Screening Test Phase Sound localization relies considerably on HRTF responses (cues derived from one's body) for accurate sound representation [5, 7]. Due to the current limitations of modelling personalised HRTFs [38], most VR systems employ generic HRTFs for binaural rendering, which can have negative impact on the accuracy and realism of virtual sound perception and hinder sound localization and perceived distance [7, 17]. Therefore, testing for sound externalization is important when evaluating binaural audio feedback via headphones using a generic HRTF. Even though precise sound localisation was not essential for the study, we ran the screening test to determine if the majority of participants could

perceive the audio spatialization with the HRTF used for the experiment. To do so, participants were immersed before to the main experiment in VR in a simplified version of the room from the main experiment to reduce the amount of visual input. They were asked to face forward, listen to a series of finger clicks and decide whether the sounds were externalised (appearing to come from outside their head) or internalised (appearing to come from inside their head); then to select their answer using a hand-held controller. The test consisted of eight trials, of which six were spatialized in different locations, and two were non-spatialized. Results showed that the majority of participants (22) could correctly perceive internalisation changes, so we deemed the generic HRTF appropriate for use.

Experiment Phase Participants were asked to sit on a stool in a neutral position and were immersed in VR with an HMD and wearing headphones (see Figure 1, second). They were not in a quadruped position, as we were interested in a more challenging embodiment (different posture between avatar and participant) and also deemed it more likely in the case of virtual experiences that the human would be in a bipedal pose, which is encouraged by Krehov et al. [23]. Participants were given a brief about the experiment, stating that they would be immersed in a dog shelter IVE embodied in a virtual dog and be able to see their reflection (as their virtual dog representation) in a virtual mirror (see Figure 2). In addition, they were informed that during the immersion phase, they would see themselves being brushed by a virtual character while simultaneously receiving different kinds of sensory feedback and that following each of the four conditions, they would be asked to complete a questionnaire using a hand-held controller. The scene represented a dog shelter and contained other virtual dogs in cages to increase its plausibility. The virtual dogs were animated with light and natural animations to provide realism to the scene without distracting participants.

Using the left handheld controller, the experimenter triggered a threat that involved the virtual avatar assaulting the dog with a syringe in a threatening and forceful manner after approximately two minutes of immersion, mimicking a lethal injection (see Figure 2, left). The threat was activated when participants looked at themselves in the mirror, allowing them to watch the virtual character's actions clearly. It was introduced as we were interested in measuring subjective response to threat as an effect of participants' embodiment (self-location and body ownership) towards the dog. Consistently with prior research [11, 15, 52], user's avatar behaviour was not artificially modified during the threat, and participants body was not really threatened.

3.1.5 Measures

The questionnaire was composed of 7-point Likert scale questions from *strongly agree* to *strongly disagree* related to embodiment. We used Roth et al.'s questionnaire [37] because it was previously used for animal embodiment measure [23] and suited our study as we consider 2 (ownership and change) of the 3 factors used in the questionnaire. This questionnaire comprises questions to assess the sense of Ownership, Agency and Change towards the virtual body. Because our experiment controlled design did not allow participants to move the dog avatar's limbs, we did not include questions related to agency, which does not impact measures of the other embodiment dimensions. One question was adapted to the experiment ("human" replaced by "animal"). Threat-related questions were included from Peck and Gonzalez-Franco [33]. Because there is no standardized questionnaire related to animal embodiment in VR, we also added specific questions for this study. In particular, we added a question to assess if participants felt like they had a fur, and another question on how warm they felt during the experiment on a scale from -3 (much too cold) to 3 (much too warm) in order to explore a potential behavioral effect of being embodied in fur through self subjective ratings. Moreover, we were interested in measuring participants'

Table 1: Questionnaire used in the experiment.

ID	Question
OW1	It felt like the virtual body was my body.
OW2	It felt like the virtual body parts were my body parts.
OW3	The virtual body felt like an animal body.
OW4	It felt like the virtual body belonged to me.
CH1	I felt like the form or appearance of my body had changed.
CH2	I felt like the weight of my own body had changed.
CH3	I felt like the size (height) of my own body had changed.
CH4	I felt like the width of my own body had changed.
T1	When the needle prick happened, I felt the instinct to move to avoid it.
T2	I had the feeling that the syringe might harm me.
F1	<i>I felt like I had a fur.</i>
W1	<i>How warm did you feel during the immersion?</i>
EM1	<i>How much would you consider donating to help the cause of abandoned dogs in shelters?</i>

Note. The element in bold has been adapted from Roth et al.'s questionnaire [37] to match the experiment's avatar, questions in italic are specific to this study, and T1, T2 are from Peck and Gonzalez-Franco's questionnaire [33].

empathy for the animal as it could be influenced by the SoE participants' experience towards the dog [1]. To do so, we measured how much money participants would hypothetically donate to help abandoned dogs in shelters, and they responded using a 6-point scale divided into \$10 increments (\$0 to \$50). In total, the questionnaire consisted of 13 questions (see Table 1).

3.1.6 Results

Parametric analyses were performed using multiple two-way repeated measures ANOVAs, with *Tactile* and *Audio* feedback as within-subject factors. For non-parametric data, the normality assumption was tested using Shapiro-Wilk test and when not verified, an Aligned Rank Transformation (ART) [50] was applied to the data. Tukey's Post-hoc tests ($\alpha = .05$) were conducted to check the significance for pairwise comparisons. In addition, post-hoc tests were corrected using Bonferroni correction. As for correlation analyses, Pearson's r (r) was used for parametric data and Spearman's r (r_s) was used for non-parametric data. Results of the questionnaire were split into the sense of Ownership (OW1-OW4) and Change perception (CH1-CH4) following Roth et al. [37] methodology, Threat perception (T1-T2), Fur Ownership perception (F1), Warmth perception (W1) and Empathy (EM1). See supplementary material for a table showing the mean scores of all dependent variables.

Sense of Ownership The analysis performed on the aggregated results of the four Ownership questions showed no effect of *Audio* but a significant effect of *Tactile* feedback ($F_{1,23} = 4.342, p = .048, \eta_p^2 = 0.16$). Post-hoc analysis showed that Ownership scores were higher in VT as compared to WVT ($p < .05$). A second analysis was also performed on each Ownership item independently, which showed higher scores of *Audio* feedback on OW1 ($F_{1,23} = 3.721, p = .06, \eta_p^2 = 0.139$). No interaction effect was found.

Change The analysis performed on the aggregated results of the four Change questions showed a main effect of *Tactile* feedback ($F_{1,23} = 9.289, p < .01, \eta_p^2 = 0.29$). Post-hoc tests showed significantly higher scores of VT compared to WVT ($p < .01$). Participants felt more *change* towards their bodies when receiving tactile feedback synchronised to the visual brushing compared to the other conditions. No main effect of *Audio* feedback or interaction effect was found.

Threat Perception The analysis performed on the aggregated results of the two Threat questions did not show any main effect of *Tactile* or *Audio* feedback and no interaction effect was found. Participants did not react to the threat over their virtual dog bodies.

Fur Perception For F1, Post-hoc tests showed significantly higher scores for VT compared to WVT ($p < .01$). Participants felt more that they had a fur with tactile feedback. Although not statistically significant, a higher *Audio* feedback rating was identified ($F_{1,23} = 3.282, p = .08, \eta_p^2 = 0.12$). No interaction effect was found.

Warmth Perception The analysis performed on W1 did not show a main effect of *Audio* feedback, only had a higher rating of *Tactile* influence though not significant ($F_{1,23} = 3.44, p = .07, \eta_p^2 = 0.13$). No effect of *Tactile* feedback or interaction was found.

Empathy The analysis performed on EM1 showed a significant main effect of *Tactile* feedback ($F_{1,23} = 7.042, p < .05, \eta_p^2 = 0.234$). Post-hoc tests showed significantly higher scores in VT condition than in WVT condition ($p < .05$). A higher score of *Audio* influence was found ($F_{1,23} = 3.27, p = .08, \eta_p^2 = 0.12$). No main effect of *Audio* feedback or interaction effect was found. Participants considered donating more money towards dogs in shelters when they had tactile feedback of the brushing compared to all other conditions. As expected, a positive correlation was found between Ownership scores and Empathy towards dogs in shelters ($r_s = 0.28, p < .01$).

Game and VR experience A ranked score was attributed to Game and VR experience self-reported by participants, in order to perform correlation analysis with other perceptive items. A positive correlation was found between Ownership scores and Game Experience ($r_s = 0.30, p < .01$), but not with the other SoE dimensions (Change and Threat) or sense of warmth. No correlation was found between VR experience and the other components. This analysis suggests that participants with more gaming experience were more likely to feel a strong sense of ownership towards the dog avatar.

3.1.7 Discussion

In this study, both audio and tactile feedback were investigated in an attempt to enhance the sense of embodiment towards a quadruped body shape. Audio feedback was provided in a novel way by the sound of fur being brushed from a first-person perspective, and tactile feedback was provided by simultaneous brushing of the participant's body with a real hairbrush.

Referring back to our hypotheses, H1 was not validated. This means that the addition of our naturally-recorded spatial audio feedback to the visual stimulus did not improve the SoE. While this result contrasts with works showing that audio feedback contributes towards changing one's mental body representation [47], it seems to be in line with the few other previous works investigating audio on embodiment [29, 42]. More curiously, H2 was not validated as we did not find that audio improved significantly other conditions.

We identified several limitations in this study. First, we decided to differentiate from the literature by using continuous synchronous audio feedback related to body characteristics such as fur. While this feedback did not improve embodiment when introduced alone, we believe it could partially be due to the fact that our audio recording did not live up to participants' expectations of what brushing fur should sound like, or perhaps, that the audio feedback did not provide accurate cues about the sound being evoked. Brushing sound is essentially noise, making it challenging to distinguish from other sounds. Although not significant, higher ratings of audio influence were observed on one ownership item, fur perception and empathy, reinvigorating the need to deeper explore their perception with audio feedback.

Second, our threat did not seem to cause a reaction in the participants. We believe this may be due to the syringe animation not being surprising or threatening enough. Alternatively, it could be due to the location of the threat being in a place where the participant did not feel embodied. However, participants did report feelings of change in their body form, implying that a morphological change was induced. Future work could try to determine if participants felt

mainly embodied in the head of the dog or if they felt full embodiment over the back and legs, etc. Additional objective measures of embodiment could also be explored, such as actual body temperature changes to combine with subjective warmth questions.

Another unexpected result was that audio did not improve tactile feedback. We suspect this is because the audio feedback was not a strong enough stimulus to provide an added effect over tactile feedback or due to the incongruency between the brushing sound and the actual tactile sensation of the brush on participants' clothes. Also, since we intended for participants to have a natural experience and be fully immersed in the shelter scene to elicit empathy towards the dog, they were not explicitly instructed to look at their reflection and focus on the brushing. Therefore, participants occasionally looked around, exploring the scene. It is possible that losing focus on the brushing could have caused the weakening of the tactile and audio effects.

3.2 Experiment 2

To further investigate the influence of audio feedback on the SoE, a second experiment was conducted. Since Experiment 1 did not offer statistically significant results on the audio-only condition, we sought to improve the audio stimuli. We implemented a new scenario of hair-trimming action performed by the virtual character. The sound of scissors cutting hair is more distinct and easily recognizable than the predominantly white-noise brushing sound while allowing the virtual scissors animation to remain in contact with the fur of the virtual dog. Additional motivations to conduct this experiment included an improved threat, longer embodiment time, and further instructions to participants to look at themselves in a mirror during the exposure.

In the IVE, an animated virtual human character trimmed the hair of the dog avatar while participants synchronously received either audio or no additional feedback (control condition). The experiment followed a within-subjects and counterbalanced design with *Sensory Feedback* as the main factor with two levels depending of the sensory feedback provided to participants:

- Audio (VA): spatialized pre-recorded scissors sounds played synchronously with the movement of the virtual scissors opening and closing;
- Control condition (V): no additional feedback, only visual feedback of the hair trimming, using a particle system to generate hair particles flying through the air away from the body.

We believe that introducing a sound that provides clearer audio cues of the virtual character's actions will elicit a stronger SoE over the dog avatar. We propose that reducing the number of conditions will enable us to increase the embodiment duration of each condition and help to prevent repetition that could induce boredom in participants. Therefore, our primary hypotheses are:

H3 VA will induce a stronger SoE compared to V.

Given the lack of significant effect shown with the lethal injection threat and the potential ambiguity of the related action, we introduced a new threat in this experiment. To make the danger more prominent and perceptually evident, we employed a ceiling light falling from the ceiling for participants to react to (see Figure 2, right). To account for individual differences in empathy, participants filled out an Interpersonal Reactivity Index (IRI) questionnaire [10] which measures four subscales of empathy (perspective taking, fantasy, empathetic concern, and personal distress) and its correlations. We chose to employ this questionnaire as it was found to be correlated with empathetic behavior in animal embodiment studies [41]. As this experiment builds upon the first, all components, including the IVE, virtual dog, apparatus, screening test, experiment procedure, and measures, were retained to ensure methodological consistency.



Figure 2: Threats used in Experiment 1 (left) and Experiment 2 (right) seen in participants' first-person view.

3.2.1 Sensory feedback

In the virtual scene, an animated human character trimmed the hair of the dog avatar (see Figure 1, fourth). The trimming animation covered the same areas of the dog's body as the brushing animation of Experiment 1: the back's center, the back's right side, the back's left side and the left forelimb. To ensure that participants had enough embodiment time, the number of loops was increased so that participants were immersed for 2:30 minutes for each condition. Of the total immersion time, participants were asked to look around and experience their surroundings for the first 30 seconds. Afterwards, they were instructed to look at the mirror for the rest of the immersion to ensure participants focused on the mirror and their reflection for the remaining 2 minutes as done in previous studies [22, 32].

Audio feedback Similar to Experiment 1, the auditory scene included sounds to induce a SoE and to increase the plausibility of the scene. The scissor sounds were monophonic audio samples of scissors cutting hair that were edited to trigger in synchrony with the animation of the scissors. Besides, to provide the same coherent and dynamic auditory cues and preserve a similar immersion level as in Experiment 1, all the contextual sounds and the virtual acoustic response of the IVE remained the same.

3.2.2 Participants

We performed an a priori power analysis using the same parameters as in Experiment 1. However, the number of measurements was reduced to two to account for the experimental conditions. Over one week, 34 participants took part in this experiment. Participants were recruited in the same way as for Experiment 1. Prior to the experiment, participants read and signed an informed consent form and completed a demographic questionnaire about age (between the ages of 18 and 51, mean/s.d. age: 23.6±7.2), gender (17 males, 17 females), ethnicity (13 Asian or Pacific Islanders, 3 Black or African Americans, 18 White Caucasians), experience with VR (1 expert, 7 moderate users, 10 sporadic users and 15 never used) and experience with video games (5 experts, 17 moderate users, 11 sporadic users and 1 never used). The screening test results showed that the majority of participants (32) could correctly distinguish internalisation changes between sources.

3.2.3 Results

The same measures as in Experiment 1 were considered in addition to the IRI questionnaire [10]. Also, to ensure methodological consistency, the same analysis method of Experiment 1 was used (see Section 3.1.6) but this time multiple one-way repeated measures ANOVAs were performed in order to search for effects of *Sensory Feedback* on the dependent variables. See supplementary material for a table showing the mean scores of all dependent variables.

No significant impact of *Sensory Feedback* was found on any dependent variables (Ownership, Change, Threat, Fur and Warmth Perception, and Empathy), nor on individual items (e.g., OW1, OW2).

Based on prior research [11, 34], we assessed the possible effect of gender on the results by conducting two-way ANOVAs with gender as a between-groups factor. A main effect of gender was found on OW2 ($F_{1,32} = 5.284, p < .05, \eta_p^2 = 0.141$), F1 ($F_{1,32} = 5.057, p < .05, \eta_p^2 = 0.136$) and TH1 ($F_{1,32} = 6.900, p < .05, \eta_p^2 = 0.177$). Post-hoc tests show higher

scores for female compared to male participants for OW2, F1 and TH1 ($p < .05$ each).

No correlation was found between IRI scores and empathy (EM1) scores, nor with any of our dependent variables except Threat ($r_s = 0.38$, $p < .001$). Interestingly, compared to experiment 1, no correlation was found between Ownership and empathy (EM1) scores.

3.2.4 Discussion and Limitations

In this experiment, we further studied the influence of audio feedback on animal embodiment. The audio feedback was provided in synchrony with the scissors animation.

H3 was not validated as our audio feedback alone did not elicit a better SoE towards the dog avatar than without it, despite the efforts in improving its quality compared to experiment 1. Our result is in line with another study that explored audio feedback in VR to elicit embodiment towards a virtual body [42], yet their experiment combined audio with visuo-motor feedback, which we avoided in our study to isolate the impact of audio-only. Our study, therefore, seems to indicate that inducing a SoE towards a virtual body using audio feedback alone is potentially more complex to achieve than the methods used in this study. This is further discussed Section 4.

In experiment 2, we also decided to include the questionnaire IRI that aims to measure subscales of empathy, and which was found to be correlated with empathetic behavior for participants embodied in virtual animals [41]. Curiously, in our study, no correlation was found between IRI scores and empathetic behavior. However, the measure of empathetic behavior differs from theirs (hypothetical amount of money to give to shelter associations compared to perceived pain related to the distress event in the game), which might explain the difference. Furthermore, we searched for the influence of gender in experiment 2 because previous work already highlighted its potential influence on the SoE [11] and because our sample size was bigger than in experiment 1 which was necessary to conduct such analysis. Again, to our knowledge, the influence of gender was never before observed in embodiment studies towards dysmorphic avatars. While our findings suggest that female participants felt more embodied in the animal avatar, we cannot be certain if this is due to gender differences or other biases between the two samples.

4 GENERAL DISCUSSION

In this paper, we investigated the relative influence of audio and tactile feedback on the SoE towards a dysmorphic avatar, and in particular, towards a virtual dog. We did not validate our hypotheses regarding the influence of audio feedback alone to elicit a stronger SoE towards the dog avatar compared to only visual feedback. While this was achieved in previous work when audio was combined with visuo-motor feedback [42], our results seem to confirm that this combination is necessary to observe beneficial influence over the SoE. Yet, it is important to note that some tendencies of audio influence were observed and that subjective scores were consequently spread, highlighting strong variability in participants' answers.

Because the differences between humans and animals are important (morphology, fur, etc.), it might be that independently of the stimulation (audio, tactile), removing visuomotor feedback makes it too challenging to feel embodied in such non-human characters. Besides, it would be interesting to see how our results might transfer to a human character in future work.

Previous work showed that personality traits could influence one's SoE towards a virtual anthropomorphic avatar [11]. Yet, whether individual differences such as personality traits could influence embodiment towards non-anthropomorphic avatars remains unclear. In our second study, we measured another personality trait - an empathy trait (IRI), which was correlated with our threat dimension of Peck and Gonzalez-Franco's embodiment questionnaire [33]. This reinvigorates the need to explore further how other personality traits may influence the challenging SoE towards a dysmorphic avatar.

5 LIMITATIONS AND FUTURE WORK

While we explored in this paper the improvement of embodiment towards a virtual dog by enhancing the feeling of having a fur, we believe future work should further investigate the potential for using material properties of the avatar to enhance embodiment - such as clothing sounds for human embodiment, feathers for a bird, etc. In particular, we highlighted several limitations in our studies that we believe would be worth investigating further in the future. First, the audio feedback provided was the result of an action performed by the virtual character and not directly a result of participants' interactions with the dog avatar. For this reason, we believe other body-related sounds would be worth investigating, such as footsteps or barking, as possibly easier to identify and from a first-person perspective.

Second, none of our subjective measures of embodiment were impacted by audio feedback only, even the one related to threat perception. This raises the question of possible ambiguity regarding whether the threat was perceived from a first-person or third-person perspective (fear of one's own body being hurt vs. fear of an animal being hurt), but also the limitations of subjective questions. We believe additional objective measures of embodiment should also be explored in this context, such as actual body temperature changes in combination with subjective warmth questions. Moreover, previous studies in animal embodiment use different measures and questionnaires making it challenging to compare results across studies. Therefore, in order to establish a clearer definition of animal embodiment and its underlying mechanisms, it would be valuable to build a standardised questionnaire with measures that take into account key features and components of animal embodiment such as posture, shape, control, agency, empathy, etc.

Besides, it is to be noted that our experiment only provided control over the animal's head to preserve first-person point of view, but did not provide full-body tracking as we wanted to avoid having too many factors of influence over the SoE towards the dog. However, it would be interesting to explore if adding visuo-motor feedback would interfere with the impact of audio-tactile feedback on the SoE.

Finally, investigating empathy towards the animal was not our main goal in this paper, though we found in Experiment 1 an effect of increased perspective-taking with higher embodiment. However, in experiment 2 no correlation was found between empathy and ownership. These effects are important to enhance pro-social behaviours, and previous work by Slater and Banakou [43] has shown that a double model of VR exposure can enhance this further. It could therefore be envisioned in future work to allow not only the embodiment of participants in a dog but also the embodiment of the virtual character that threatens it and investigate its influence in enhancing empathy and pro-social behaviour. Moreover, while animal embodiment is expected to induce empathy and have positive implications towards animal welfare, the long-term effects of embodying an animal on the user are yet to be explored.

6 CONCLUSION

In this paper, we explored alternative factors that could be used to induce embodiment of a non-human character. We introduced a novel audio-tactile feedback through continuous brushing or cutting of the virtual fur to enhance the feeling that the human's skin was covered in fur. It was the first time that audio-only feedback (without visuo-motor or visuo-tactile feedback) was studied to elicit a SoE towards a non-human avatar. We believe our research provides interesting insights into this much under-explored topic, and hope that future work will investigate further novel feedback methods to provide a SoE towards non-human avatars.

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