Hum-ble Beginnings: Developing Touch- and Proximity-Input-Based Interfaces for Zoo-Housed Giraffes' Audio Enrichment

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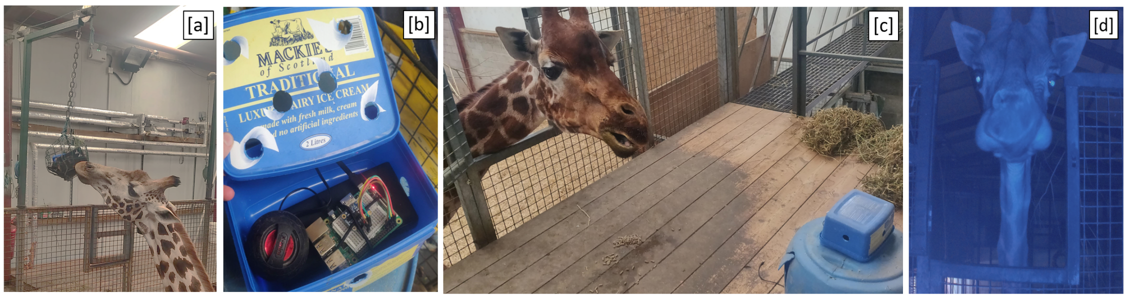

Fig. 1. A giraffe interacting with a touch-based audio player (a); the touch-based device hardware (b); giraffe interaction with a proximity-based player (c); and an image, from the player's camera, of giraffes attending to its audio (d).

Though computer systems have entered widespread use for animals' enrichment in zoos, no interactive computer systems suited to giraffes have yet been developed. Hence, which input modes or audio stimuli giraffes might best utilise remains unknown. To address this issue and probe development of such systems alongside the animals themselves and zookeepers, researchers gathered requirements from the keepers and from prototyping with giraffes, then created two interfaces – one touch-based and one proximity-based – that play giraffe-humming audio or white noise when activated. Over two months of observation, giraffes utilised the proximity-based system more frequently than the touch-based one but in shorter episodes. Secondly, the study highlighted the significance of considering user-specific needs in computer systems' development: the lack of preference shown for any specific audio type indicates that the audio stimuli chosen were inappropriate for these giraffes. In addition, the paper articulates several lessons that can be drawn from human–computer interaction when one develops systems for animals and, in turn, what the findings presented mean for humans.

CCS Concepts: • **Human-centered computing → User interface design**.

Additional Key Words and Phrases: Interaction Design, Animal–Computer Interaction, Zoo–Computer Interaction, Audio Interfaces

1 INTRODUCTION

As more giraffe species come under threat, the likelihood of their preservation largely in zoo spaces rises [11]. While giraffes in the wild experience varied stimulation from changes around them, grazing opportunities of several sorts, and free-roaming, these do not exist to anywhere near the same extent in captivity [3]. Creating a stimulating environment for giraffes housed in zoos poses a constant challenge [10, 12]. Notwithstanding efforts to grapple with this issue, giraffes often exhibit boredom-linked behaviours – tongue-rolling, excessive licking of non-food objects, etc. [3]. To engage these animals and, via stimulation, forestall such negative manifestations, zoos employ so-called enrichment: efforts to enhance captive animals' psychological and physiological welfare by promoting positive species-appropriate behaviours [15]. Today's enrichment solutions often rely on food-based toys and 'foraging puzzles'. However, since the necessary

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careful management of the animals' food intake restricts use of such items [12, 34], zoos are turning more and more to computer systems, in ever-increasing variety, to provide non-food-based enrichment while also probing the cognitive and behavioural needs [8, 14, 48]. Building appropriate interactive computer systems is not easy, though, in that the technologies must be aligned with the animals' complex nature and requirements [50]. Because animals differ not only in their needs but also in abilities, the interface has to elicit suitable physiological and cognitive responses analogous to what the zoo animal in question would exhibit in its natural habitat [29]. Tackling these challenges head-on, the animal–computer interaction (ACI) discipline has, with the goal of supporting animals' well-being, undertaken to investigate interactions between non-human animals and computers [27].

Many of the non-food-oriented interaction systems implemented in zoos are audio-based. These computer interfaces vary, allowing the animal to play human music [25, 36, 39], synth tones [14], sounds from nature [36, 39], or a subset of the animals' vocalisations [44, 47]. In addition to providing choice and enrichment for the enclosure, most devices let the animal turn these sounds on and off, thereby aiding in ascertaining preferences [14, 25, 36].

Most ACI efforts involving audio-playing computer devices focus on monkeys [36, 44, 47], great apes [39], parrots [25], and elephants [14]. The literature points to the possibility of this avenue for effective non-food-based enrichment for other species too – giraffes in particular. They have sharp hearing, and the humming noises they make at night, at least when in captivity [2] attest to potential: while the meaning of this humming remains unknown, we know that such vocalisations are integral to their communication and other behaviour [2]. We hypothesised accordingly that audio-based computer devices utilising these humming sounds could constitute effective enrichment for giraffes.

To explore interactions between giraffes and computers, we built a giraffe-controlled device that facilitates triggering of audio clips. This entailed gathering requirements in zoo settings by testing several kinds of interfaces and clips. Proceeding from our findings, we developed two systems, one activated by the giraffe standing in front of the device and a touch-based system that can be triggered by headbutting, licking, or nudging of the device. Deploying these systems in parallel for two months with a five-giraffe tower, we measured interaction duration and activation frequency. Both systems were designed to play either giraffe humming or white noise. This set-up enabled gauging their preferences for modality and audio type in the enclosure, in a research project structured around the following questions:

RQ1: How does modality affect the way in which giraffes use computer interfaces?
RQ2: What type of audio do giraffes trigger when given a choice?

In our study, giraffes expressed indifference with regard to the choice between audio types and, moreover, demonstrated a preference for conditions in which no sound was played. This indicates that neither giraffe humming nor white-noise audio constitutes effective enrichment for this group.

As for their choice of mode, the giraffes studied triggered the proximity-based device significantly more often than the other one but interacted longer with the touch-based device per instance of triggering. We conclude, therefore, that proximity-based devices were the preferred input mechanism as judged by frequency while touch-based interaction showed superiority in terms of prolonged engagement.

In the course of producing the first interactive device built for zoo-housed giraffes' computer-based enrichment, the research articulated a solid process for creating giraffe–computer interfaces. The framework thus forms a foundation for developing further systems of its kind. This work with non-human animals simultaneously informs the human–computer interaction (HCI) domain with insight for catering to users with complex needs and a broad spectrum of ability to understand technology. Furthermore, careful attention to humans' part in the process – in our case, the zookeepers alongside the animal user – afforded exploring the intersection between human and animal technology. On this basis, the paper highlights how prior assumptions can influence design decisions when HCI methods are adapted to ACI domain in various respects.

2 RELATED WORK

In their investigation of how animals interact with certain interfaces and novel technologies [27], ACI researchers frequently develop prototypes and full systems from an HCI point of view [53]. One vital feature being that the ACI developer creates from the perspective of a user not supplying spoken or written feedback [28]. While a wide range of animal species can benefit from ACI, most early efforts involved household and farm animals, thanks to ease of access [4, 17]. Recent years have witnessed increased research at zoos, however [10, 25, 27, 51], which has yielded evidence that computers can both enrich animals' life and enhance our knowledge of their behaviour and cognition [8].

2.1 Interactive Computer Systems for Zoo Animals

Complementing cognitive testing, which historically accounted for most research on animals in captivity [29, 35], an emerging stream of animal-computing studies investigates how computers can afford zoo animals' enrichment [8, 36]. Zoos often encourage species' preservation by means of foraging tasks, toys, and puzzles for the animals kept in their facilities [12], non-technological items intended to trigger the animal's instincts and, thereby, elicit nature-parallel behaviours [12]. The above-mentioned addition of computer-based interactive systems to the landscape dovetails well with husbandry practices tuned to improving welfare and minimising stereotypic behaviour, thus supporting a focus on choice-centred techniques [29] in the evolution of what the zoo community calls environmental enrichment. Many researchers in this field see potential in using computers to stimulate natural instincts in animals (a phenomenon termed 'functional naturalism'); it is widely believed that computers can offer zoo-housed species challenges similar to those they would encounter in the wild [29, 45]. For instance, Martin and Shumaker [29] have concluded that zoo-housed apes performing problem-solving tasks with touchscreens call upon behaviours and cognitive-processing mechanisms similar to those activated during their wild counterparts' foraging, planning, and navigation tasks.

Presenting choices is fundamental to these zoo technologies. While meeting the animals' needs for food, water, shelter, and veterinary care is necessary for their well-being, it cannot on its own guarantee good welfare [24] – there is also a need to ensure the animal's agency, its ability to make meaningful choices and control core aspects of its life [20]. Agency can be more precisely defined as a natural tendency or inclination to engage actively with the environment so as to gather knowledge and advance one's skills [45]. A recent trend in ACI research has drawn the field toward technologies that facilitate animals' use of technologies – e.g., to augment aspects of their enclosure [16]. For further delineation of animal rights in the technology sphere, some scholars [19] employ the term 'technologies for choice' to identify a right for animals to be treated within computer systems as individuals rather than property.

There are numerous examples of animals in zoos using technologies for choice. Marmoset monkeys granted control over their enclosure's lighting and temperature have manifested calmer behaviour and better welfare [5]. When investigating a different sort of implementation, a graphical interface developed to let Japanese macaques select videos to watch [33], researchers found that animals given control of the video presentation spent more time in front of the display and exhibited fewer abnormal behaviours. A project with elephants, in turn, found that when elephants could control it, the music-playing interface under study became woven into their sensory/aesthetic experiences and provided cognitive enrichment [15]. These studies all demonstrate the importance of a computer-system design that enables the zoo animals' easy use and control of the device, if it is to yield maximal enrichment and engagement.

As these cases hint, zoo technologies for choice vary greatly in the interfaces developed to facilitate agency, among which are switches [5, 15], joysticks [25], use of space [21], projections [8], and touchscreens [35]. Nonetheless, many computer systems designed for animals employ only one interface variation. Thus they constrain the animal's choices related to interaction while also impoverishing the data-gathering experience.

2.2 Interfaces and Modality in Animal–Computer Interaction

To address animals' choice of mode and other elements, researchers have recently turned to co-design and other participatory methods that facilitate testing multiple low-fidelity interfaces with these users [15, 19]. Prototyping various interfaces in this way helps human designers consider how to map the device-provided affordances to the animal's needs/desires [19]. Outspoken advocates of testing with the actual animal users, Byrne et al. [7] illustrated the point by reporting on dogs successfully using the nose to activate icons by touching. Building on this, the Hirskyj-Douglas team [19] tested various toys with a dog to pinpoint design factors for a dog-to-human video-call interface. The dog's preference for a ball-like device with soft aesthetics contributes to a valuable knowledge base, as does work wherein Robinson and Torjussen [40] found that button-using dogs choose to use their paws and that they appreciate both tactile and (swift) auditory feedback. A final example of interface affordances' vital role in the use of the device comes from Kankaanpää and Hirskyj-Douglas [22], whose testing of various button interfaces with white-faced saki monkeys uncovered a preference for pull-and-swing interfaces over touch-and-push ones and for brightly coloured buttons.

Such joint exploration helps designers understand how animals use particular interfaces [7, 41]. It shows potential to address an irony now evident in animal computing: one could argue that the interfaces of 'systems for choice' remain limited. Inadequate interfaces, born of insufficient understanding, represent a gap that could be filled via deeper investigation of how animals wish to interact with systems – i.e., of input modes. One could ask about output modes too, but this is beyond the scope of this paper.

As for species-specific work, no prior research whatsoever has examined developing computer systems for giraffes. Investigations with these species have been limited to a study with non-technological food puzzles [12] and one assessing their scent preferences via smell-based enrichment devices [10]. Although neither project led to enough enrichment to reduce the incidence of stereotypy, they demonstrated that giraffes have preferences and can make choices related to their enclosure. As the rising number of giraffes in captivity renders choice all the more important for the species' welfare, the need to explore how computer systems can support giraffes' enrichment and what interface types mesh with this (RQ1) grows all the more apparent.

2.3 Audio Enrichment

Many technologies for choice have been designed to facilitate animals' selection from among various audio stimuli and turning the stimuli on/off [25, 36, 44, 47]. In a zoo context, they have functioned to help create bonds linking the animals, their keepers, and visitors to the zoo [25]. With audio being a key channel of communication by and with animals [14], creating a tool to facilitate animal–animal or human–animal connection could prove to be an enriching experience for all parties involved [25]. However, many audio-enrichment efforts exhibit mixed results, partly because each species and individual reacts uniquely to audio. Research highlights vast variation in preferences [36].

For example, saki monkeys seem to prefer road-traffic audio [36] while orangutans opt for silence [39]. Tamarin monkeys [44], in turn, seem calmer and less agitated overall when exposed to audio specially constructed from tamarin vocalisations [44]. They are indifferent to human music, whereas elephants exposed to classical music have shown signs of improved welfare [14], exhibiting less stereotypy in their later behaviour and displaying a calmer demeanour [51]. Frequency plays a part in this phenomenon – elephants prefer lower frequencies of music, with French et al. [14] identifying the best-received audio samples as lying in the 60–80Hz range (noteworthy for its overlap with the range of natural elephant noises). Several studies suggest that animals often do not favour human-based music so much as favour traits of species-based audio that involves the animals' calls or audio at their typical call frequencies. For instance, playback of affiliative calls simulating nearby friendly marmosets stimulated a zoo's marmosets to display extended affiliative behaviours (allogrooming, grooming invitations, affiliative contact, and food-sharing) even after playback had ceased, thus improving their welfare [47]. In light of the research results' multifaceted nature, there was no obvious conclusion as to what audio giraffes would prefer and whether they might favour species-based audio (RQ2).

3 STUDY PARTICIPANTS

The participants in our study were five female hybrid-species giraffes, *Giraffa camelopardalis*, who had been living together for the preceding 10 years at *Blair Drummond Safari Park*, in *Stirling, Scotland*. No hierarchical structure was visible among the members of the group (aged 13, 14, 17, 22, and 24 years), and only the eldest and youngest giraffe, a mother and daughter, were related by blood. These giraffes had no prior experience with interactive enrichment technology or medical computerised devices, and there was no automated technology in their two-part enclosure. For the night, all of the giraffes were kept in the indoor area, composed of three sections, each of which is 10 metres high: a larger pen (approx. 20m wide) and two medium-sized pens (roughly 8m wide) that have concrete floors and are visible to visitors from a viewing platform. During the day, the giraffes could move between that portion of the enclosure and an outdoor part. The giraffes sometimes shared their living space with zebras, so the technology was placed at giraffe height to prevent any interference from cohabiting zebras.

4 DESIGN REQUIREMENTS FOR COMPUTER SYSTEMS FOR GIRAFFES

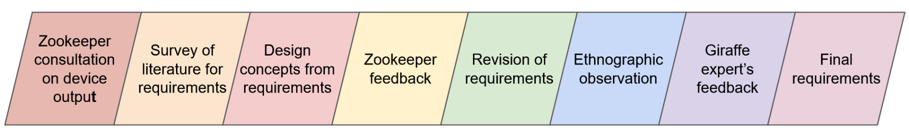


Fig. 2. The stages of the requirement-gathering process for giraffe technology

In the absence of literature on computer-based audio work with giraffes, we began with a foundational phase examining system and design requirements, to specify the functions required. For the animal-computing design process, requirement-gathering is especially pivotal [53]. After initial consultation with zookeepers to establish that the output stimuli would consist of audio, core requirements outlined on the basis of previous audio-enrichment research assisted us in creating design-concept sketches for the system. Next, consulting the keepers again, for their opinions on the prototype concepts, led to revision of the requirement specifications. Ethnographic observation of the tower constituted the next stage. Then, consultation with a giraffe expert aided in finalising the list of system requirements. Throughout the study, we adhered closely to ethical-practice recommendations, such as the European Association of Zoos and Aquarium Research Standards [9], and we obtained approval from the zoo's research board and the *University of Glasgow's* ethics board.

4.1 Work with Zookeepers To Develop the Stimuli

We began by identifying what audio output the device should play. To do this, we perused scientific reports documenting giraffes' primary senses – e.g., their excellent hearing, vision, and sense of smell [23]. Then, we consulted the keepers who were looking after the giraffes. They ruled out visual cues, because of worries that devices employing these, however promising an avenue, might not prove robust enough. To honour the objective of choice, we subsequently excluded smell too. Since no current technology can reliably turn smells on and off, a giraffe's ability to control smell-based systems would be limited. Ultimately, the zoo staff were keen on an audio-based system, given the recent literature on sounds made by giraffes [2]. This decision to pursue an audio-based interface was supported also by audio-enrichment work conducted with elephants; evidence exists that large mammals respond favourably to audio-based devices [14].

4.2 Requirement-setting for Audio-based Interaction with Giraffes

To identify the initial requirements, we consulted literature on computer-based auditory enrichment for zoos [15, 18]. We identified the following requirements accordingly: the system must not require training (R1), could not negatively influence welfare (R2), must not produce loud noises (R3), must not create dependency (R4), and has to provide control and choice (R5).

In the next stage, we sought feedback from the giraffes' keepers with regard to modality for the audio-based system. Since envisioning new systems with potential for zoos poses challenges on multiple fronts, we devised several system ideas as starting points. To assist with ideation and ensuring that the designs met the requirements (R1–R5), we brought in ACI experts. The work produced three main ideas: a tongue-activated hanging ball that plays an audio clip corresponding to the hole selected (Ball Chimes), a hanging ball that responds to its motion by playing audio samples (Ball Twiddler), and a proximity-based interface called Piano Stamp in which the key below the giraffe's head dictates which of various tones gets played. Sketches for these were shown to three of the giraffe-keepers, all of whom had been working with the tower for at least three years; in addition, the zoo's head of research provided feedback in a less formal interview setting. Interviewing the keepers who care for the animals has become standard practice in ACI [53]. It contributes to system designers' awareness of differences between individual animals and of their specific needs. The feedback in this case included emphasising a desire for the system to be readily accessible to staff, so that they could manoeuvre the device around the enclosure (R6) and stressing that it should be low-maintenance and easy to set up (R7). Keepers commented also on the aesthetics, recommending that we pattern the system on the zoo toys already used in the enclosure – making the system more familiar to the giraffes should encourage interacting with it sooner (R8). Since they lacked time for training the giraffes in interface use, keepers asked in addition for intuitive input; that is, the interaction technique developed had to be simple enough to support the animal's unassisted use of the system (R9).

The ethnographic observation that followed was aimed at creating a genuinely intuitive interface informed by deeper insight related to daily behaviours. Ethnographic examination of animals' technology use is consistent with animal-computing designers' methods of helping create the interface and measuring the final system's effectiveness [52]. Observing the tower for two days, we looked specifically at how the giraffes interacted with their feeding toys and during the enclosure's cleaning. One factor we noted is that, to release all of the food from their hanging feeding toys, the giraffes flung them upside down with levels of force that could easily break an insufficiently durable system. This gave rise to a robustness requirement (R10), the importance of which was accentuated by the fact that the giraffes licked all of their toys and even parts of the enclosure: protection against exposure of any circuit board dictated sufficiently sealing or covering the technology developed. Furthermore, we identified a need to protect the system from splashes of water at cleaning time (R11). Finally, walking around the enclosure enabled us to identify an installation location satisfying our technological and logistical requirements – in the main, line-of-sight alignment with the enclosure's camera, to validate interactions (R12), and access to a Wi-Fi signal and power supply (R13).

Armed with this knowledge, we proceeded to the final requirement-gathering step: consulting an expert in giraffes' vocal-production mechanisms who researches acoustic communication involving giraffes. This was Anton Baotic, the scholar who discovered giraffe humming [2]. While he confirmed that audio holds promise in the giraffe-research arena, he advised a focus on the system's utility at night, when giraffes have demonstrated acoustic communication (a phenomenon that he speculated to involve humming standing in for visual cues). As for giraffes' manner of input, Baotic recommended relying on headbutting or on rubbing with the neck, and he advised against using food. To account for his ideas, which were aligned well with the keepers' concerns, we refined the requirement list.

This process produced the following specifications:

- **R1:** No need for training or for food
- **R2:** No negative effects on the animal's welfare
- **R3:** No loud or abrupt noises
- **R4:** Lack of addictiveness and of potential to form an unhealthy attachment or dependency
- **R5:** Provision of control and choice to the giraffes
- **R6:** Ease of access for keepers
- **R7:** Low maintenance needs and easy set-up for keepers
- **R8:** Appeal to familiar aesthetics, such as features of the current feeding toys
- **R9**: Simple yet stimulating interaction modality
- **R10**: An enclosed nature, with no vulnerability to licking/biting or to easy breakage
- **R11**: Water-resistance, to withstand cleaning of the enclosure
- **R12**: Support for remote monitoring of interactions and for video-based validation
- **R13**: A Wi-Fi connection and an electricity supply (easily swappable if relying on batteries)

Not all requirements on this initial list had to be met from the outset. We recognised that some (such as R2, R4, and R9) could be examined more fully further along in the design process and addressed in light of results from testing.

The next phase began with discussing these requirements with the keepers and other experts. Since many matters related to designing an interactive interface for giraffes remained unclear, this led to a decision to test multiple distinct input modes for exploring how giraffes may interact with audio-based devices. We chose two ideas that met all of the requirements: a touch-based motion-activated hanging device and a proximity-based device. The origins of the former lay in noticing that the giraffes were highly tactile when interacting with their environment, and their toys were centred primarily on tactile interactions. As for the proximity-based device, considerable work has examined use of such interfaces by zoo-housed animals, though mainly monkeys [21, 33] and elephants [14]. Among their other advantages are that systems of this nature do not demand any training yet still grant the animals choice (in line with R1 and R5) and can be placed at the side of the enclosure for easy access/cleaning and monitoring (thus meeting R6 and R12, respectively).

5 IMPLEMENTATION OF AN INTERACTIVE AUDIO DEVICE FOR GIRAFFES

To implement our audio-based systems for giraffes, we had to design and build two separate types of system: one responding to giraffes' physical touch and one reacting to the presence of giraffes in front of the unit. This also necessitated ascertaining which types of audio output to utilise in the interaction.

5.1 The Touch-based Interface for Giraffes' Audio Interaction

The design for our touch interface was inspired by a keeper's suggestion of modelling the interface on feeding toys already present in the zoo (R8). Per reports by the Hirskyj-Douglas team [19] and Robinson et al. [41], transforming everyday items in an animal's home can aid the animals in understanding the affordances of devices. Furthermore, modifying accepted toys suits giraffes' neophobic stance well; often, considerable time elapses before they interact with new items [43]. We inferred that using pre-existing toys' form could help the giraffes grasp the device's function more easily.

We chose four toys typically used in the animals' enclosure – the barrel, box cage, spherical-shaped cage and plastic-box board presented in Figure 3. All had enough space within to accommodate a microcomputer handily and a large hole in which the technology could be inserted. This helped ensure that no technical components could end up exposed (R10). Also, each form's moderate size supported low-fuss manipulation, thereby providing accessibility (R6), a low-maintenance solution (R7), and the ability to contain a battery pack (R13).

Before proceeding further, we placed these toys in the giraffes' enclosure to ascertain how they interacted with the various interfaces. Testing non-technical low-fidelity devices in this manner has been validated and shown to produce valuable results in projects building interactive features with animals in zoos [14, 16, 36]. The devices were hung one at a time on a bar running along the ceiling of the indoor space. Keepers had cited this as a suitable location for the system.

With the keepers' assistance, we then tested the device's installation and removal with each toy. Keepers expressed dissatisfaction with using the barrel and plastic-box board with the device; since these were too large for easy attachment to and removal from the bar, they did not fully meet R6 and R7. We deemed the other two forms the most viable options for housing the device – the keepers found them the easiest to maintain (R7) and the most accessible (R6). Ultimately, we chose the spherical cage as the final encasement for the system, honouring the keepers' request to reserve the box cage for feeding. Finally, their feedback prompted us to improved the design's sound projection by cutting holes of moderate size in the box enclosing the technology, which were rounded off so that no sharp edges could harm a giraffe's tongue (R2). Figure 4 presents the device in its finished form.

Fig. 3. Forms of feeding toys used at the zoo – a barrel (a), box cage (b), spherical cage (c), and plastic-box board (d).

No guidelines exist for evaluating the swing from a giraffe interacting with devices by touch. To measure the strength of the animals' touch with the relevant device, we placed an orientation sensor (Adafruit BNO055) inside the sphere to capture the acceleration from the giraffe-initiated swinging motions until they lost interest in the prototype (a span of 10 minutes). Recording data from a keeper installing and nudging the device enabled us to differentiate between human- and giraffe-generated touch. We could also identify movements caused by elements of the environment (such as branches and other objects in the enclosure). From the readings, we ascertained that the acceleration values originating from the environment were small <0.05m/s^2, while a human's touch typically registered at >10m/s^2, with a giraffe's being below the latter threshold and above 2.5m/s^2. We parameterised the software accordingly, to reduce the number of false positives. The hardware for the audio device with this interface mode consisted of a Raspberry Pi 3 Model B board, the above-mentioned sensor, an X-mini speaker (by Xmi), and a 30,000mAh battery pack housed in a plastic case. The orientation sensor expresses the acceleration vector as three axes of acceleration (m/s^2 from gravity and linear motion). If consecutive sensor readings exhibit changes within the limits set for the swing parameters and the force is identified as falling within a giraffe's range, system output gets triggered. Any interaction detected is logged and made accessible online, with the associated timestamp, for validation against the enclosure's video footage. The system software, written in Python 3.8, is available at *https://github.com/alanagrant18/Hum-ble-Beginnings-Project-Code.git*.

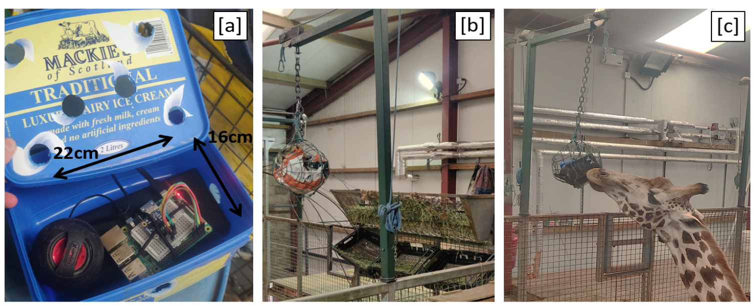


Fig. 4. The touch-based device and hardware (pane a), the system set-up (b), and a sample interaction with it (c).

5.2 The Device for Proximity-based Audio Interaction

The second prototype constructed was the proximity-based device, which had to detect when a giraffe was standing in front of the unit. To build this device, we tested an infrared (IR) sensor (Sharp GP2Y0A710KOF) with a 100–550cm range for distance measurement within the giraffes' enclosure. Because the sensor's voltage measurements depend on the angle and surrounding objects, we pinpointed parameters that reflect actions by a giraffe (in the enclosure) vs. a keeper (on the platform). Positioning the proximity-activated device 1.5 metres from the enclosure opening made it close enough for the sensor to detect a giraffe accurately but sufficiently far away that the giraffes could not lick the technology (thus fulfilling R10).

We obtained the parameters for giraffes' proximity by recording the IR sensor's voltage measurements when giraffes poked their head through the gate opening close to the location chosen. Keeper-related parameters were judged from walking in front of the device on the viewing platform. We identified 2–2.3V as denoting a giraffe and >2.4V as indicating a human.

We built the proximity-based system to play audio to giraffes on this basis. The hardware, shown in Figure 5, consisted of another Raspberry Pi 3 Model B board, the IR sensor, an RPi IR-CUT night-vision camera, an MCP3008 eight-channel

10-bit analogue-to-digital converter with serial connection, and a set of Creative MF1680 speakers attached to the rest of the system by a power cord. Housing the device in a plastic box prevented the exposed components from collecting dust. As with the touch-based system, the time and other details of all interactions detected were logged for later validation, in this case by means of the night-vision camera's images of the interaction, stored locally on the Pi. The system software is available at *https://github.com/alanagrant18/Hum-ble-Beginnings-Project-Code.git*.

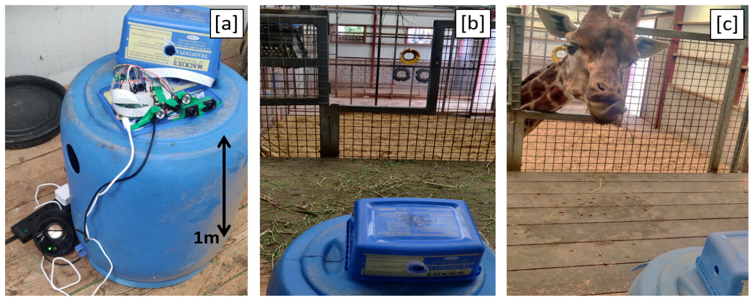


Fig. 5. The proximity-based system's hardware and set-up (a), the perspective from the installation location (b), and an instance of proximity-triggered interaction.

5.3 Audio Stimuli

The speakers for the touch-based system's audio output were housed in the plastic container, while speakers next to the device served the proximity-based system. In both cases, their balance was set for identical volume. For the audio material, we referred, firstly, to literature suggesting that species-specific noises enhance animals' well-being by promoting relaxed behaviour [44]. Creating the giraffe-specific clips involved selecting samples from the library of vocalisations provided by Baotic and colleagues [2][1]. Alongside very brief recordings (under 3s long), we excluded clips with audio echoes and protracted silence. Ultimately, we chose a set of three 13-second-long clips via this procedure. Since giraffes' vocalisations lie in the 92.01–25.78Hz frequency range, we made sure that the speakers could handle these low frequencies.

For a second audio source, we chose white noise. Researchers frequently apply this in animals' audio interfaces because its frequencies span the whole sound spectrum, uniformly [39]. We edited a clip of white noise[2] to 13 seconds, to match the length of the longest giraffe-humming clips.

By some ACI scholars' reasoning, playing back animals' vocalisations is unwise on account of humans poor awareness of what those vocalisations mean to the animals [46]. Also, such playback arguably holds potential to cause stress to the animals not least because they hear these sounds without other animals being present [30]. We accounted for this factor by creating an element of choice in both settings: an animal not wishing to hear the audio could elect not to trigger the device, by avoiding activation of the system. Additionally, we asked the keepers to watch for additional negative behaviours of the giraffes (R2), with the objective of removing the device immediately should any get spotted. At no point in the study did keepers report any such behaviours.

[1] Specifically, the humming samples from additional files 5, 6, and 7 available via https://bmcresnotes.biomedcentral.com/articles/10.1186/s13104-015-1394-3 accessible on 30 August 2023.
[2] See the Sleep Foundation's reference material at https://www.sleepfoundation.org/noise-and-sleep/white-noise, as accessed on 26 January 2023.

6 METHOD

The two systems were to be available one after the other. We implemented the touch-based system first, then the proximity-based one. To avoid associations, we implemented strong separation between the locations (the ceiling-mounted bar and the elevated platform in front of the gate) minimised interference effects. Figures 4 and 5 present the installations. While this created potential for an ordering effect, various constraints related to the research setting of a working zoo environment (such as zookeepers having to deploy the touch-based system manually) and the audio-based nature of the output meant that the systems could not be used in parallel. While it would have been ideal to have two sets of giraffes, it is not possible to separate groups in zoo settings.

To investigate the giraffes' preferences across conditions, we calculated interaction time per day from each system's interaction-log spreadsheets. Remote accessibility allowed us to assess the frequency and duration of interaction with the devices while reducing the need to enter the enclosure. To test the effect of each system, we captured a baseline from one week's presence of it without audio output, followed by data from two weeks of exposure to its audio interaction (the vocalisations and white noise). Data from the next week, with null audio, allowed comparison between pre- and post-audio-condition behaviour. This method has shown success at zoos for evaluating effects of animal technologies relative to everyday behaviour [21].

Using a longer deployment period reduced environmental variations' effect on the measurements while also decreasing the novelty effects that can appear in animals' behaviour when exposure persists for only a few hours [49, 50]. In all, the touch-based system was used for 269 hours over the 30-day span observed. This total breaks down to 42 hours for the no-audio baseline, 106 for humming, 106 also for white noise, and a 57-hour post-audio span. The proximity-based system received twice as much use, at 540 hours over 24 days (baseline: 136 hours, humming: 133, white noise: 135, post-audio: 13). We normalised the data with reference to the total number of hours, following the example of prior work [36].

Our discussions with Baotic and zookeepers informed the decision on when the systems should be online (i.e., the best timing for triggerable audio). To meet the giraffes' need for nighttime stimuli and factor in the limited indoor space, we followed the recommendation to have them available over the night hours (5pm to 9am). Furthermore, giraffe humming has been witnessed only at night [2], so such timing should provide more contextually familiar audio. A pseudo-random generator picked a single audio type for both devices to play on a given day. This selection technique was designed to avoid an ordering effect between the white noise and humming. Since average interaction frequencies were low, at 3.5 and 2.6 times per day for the proximity- and the touch-based device, respectively, this approach was important also for giving the giraffes enough time to associate the noise type in question with its trigger.

Under our participant-controlled methodology, the amount of interaction functions to indicate preference. This approach is consistent with prior work [6, 36]; however, there is considerable debate within the animal-computing community as to interactions' meaning for animal users, what they signify. With the associated notions not being entirely clear for practitioners either, we apply the term 'interaction' for an animal triggering a system while 'preference' is proxied by the frequency of triggering the outputs. We unpack these concepts in our reflections on the space between animals and computers, below.

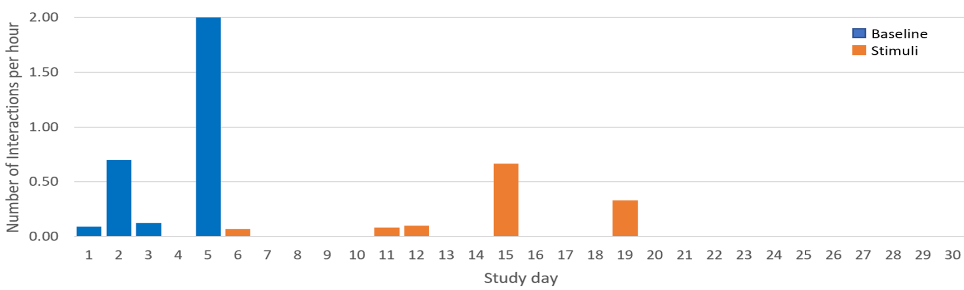
7 DATA ANALYSIS

No system failures affected either device during the study. Naturally, data analysis still necessitated preparatory cleaning and verification of the data. This data-cleaning process involved removing any interactions triggered by the keepers handling or walking in front of the device. These were identified by pairing the time-stamped interaction data with the enclosure camera's video footage and the night-vision recordings. Of the 584 interactions with the touch-based device, 496 were eliminated as irrelevant, leaving 23 giraffe interactions. From the raw total of 357 for the proximity-based device, 250 were removed, with 104 giraffe interactions remaining.

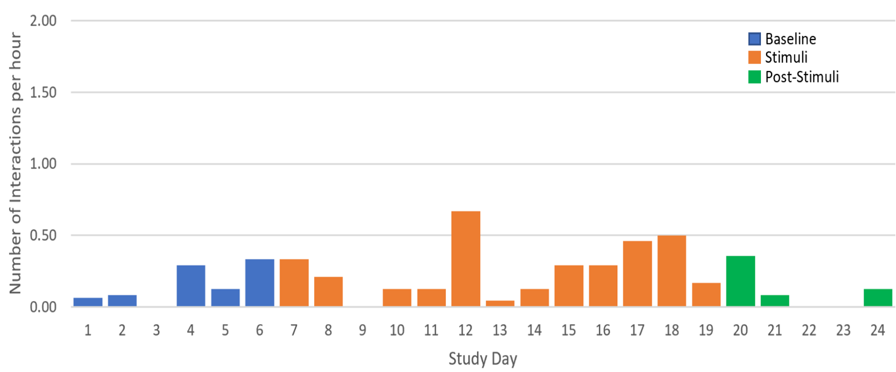
Since the study conditions were constant neither from hour to hour nor from day to day, we normalised the interaction data for relevant 60-minute intervals to compare interactions across audio types and discriminate between the two modes, assessing the results in terms of both frequency and duration. The distribution of duration, with hours as units, is skewed (in D'Agostino skewness testing, skew = 11.0, with p<.001). Therefore, we used the Wilcoxon rank-sum test, a non-parametric test suitable for unpaired data, to assess the significance of differences between total interaction duration (in hours) and the number of interactions per hour with the null hypothesis that th (H0: The giraffes' use shows no difference between modes or audio types). The resulting p-values were adjusted via the Holm method. Our statistical analysis relied on the RStudio IDE with the tidyverse package, v.1.3.2 (for data-processing and visualisations) and rstatix, v.0.7.0 (for Wilcoxon tests).

8 RESULTS

The results are presented at the level of the group of giraffes though we were sensitive to each animal's uniqueness. Below, we address what audio the giraffes triggered (RQ2), then which device mode they activated (RQ1).



(a) The tangibly oriented audio system's use



(b) Use of the proxemic audio system

Fig. 6. Interactions per hour, normalised over the study's full duration, with the touch- and proximity-triggered audio devices.

Table 1. Wilcoxon rank-sum test results for the duration of the giraffes' audio-device interactions (in seconds/hour) (* = p<.05)

Modality	Condition 1	Condition 2	$n1$	$n2$	W	Adj. p-value	Effect size (r)
Touch-based	Baseline	Humming	42	106	2678	.001*	.31
Touch-based	Baseline	White noise	42	106	2666	.001*	.29
Touch-based	Baseline	Post-audio	42	57	1482	.001*	.39
Touch-based	Humming	White noise	106	106	5569	.756	.02
Touch-based	Humming	Post-audio	106	57	3135	.294	.12
Touch-based	White noise	Post-audio	106	57	2878	.294	.13
Proximity-based	Baseline	Humming	42	106	8584	.611	.31
Proximity-based	Baseline	White noise	42	106	7990	.143	.29
Proximity-based	Baseline	Post-audio	42	57	9576	.021*	.39
Proximity-based	Humming	White noise	106	106	8244	.266	.02
Proximity-based	Humming	Post-audio	106	57	9841	.006*	.12
Proximity-based	White noise	Post-audio	57	106	7252	.000*	.13

Table 2. Giraffes' interaction frequency and duration, by study condition

		Frequency	Duration (s)			
Modality	Condition	(/hour)	Total	Mean	*SD*	Max.
Touch-based	Baseline	13	995	22.7	59.3	279
Touch-based	Humming	4	200	1.9	10.1	73
Touch-based	White noise	6	169	1.6	7.8	56
Touch-based	Post-audio	0	0	0	0	0
Proximity-based	Baseline	21	597	4.5	20.3	155
Proximity-based	Humming	30	454	3.4	11.0	77
Proximity-based	White noise	45	1119	8.4	36.8	390
Proximity-based	Post-audio	8	214	1.6	14.9	170

8.1 Giraffes' Audio Preferences (RQ2)

In conditions of proximity-based activation, white noise was triggered more frequently (N = 45); however, it was not significantly more frequent than humming (P = .266) or than interaction in the other conditions (baseline P = .143, post-audio P = .000) (1). This result indicates that the group of giraffes had no preference between the forms of material tested.

Investigating the audio preferences revealed that the most and, on average, the longest interactions with the touch-interface device occurred in the baseline setting: N = 13 and M = 22.7, with with a standard deviation SD of 59.5 (see Table 2). A marked contrast emerged with the proximity-based device, for which the white-noise condition manifested the highest numbers on both counts: N = 45 and M = 8.4, with SD = 36.8. With the latter device, the giraffes most often triggered white noise (N = 45) and humming (N = 30); see Table 2. A giraffe's median interaction/hour value was 0s for each device, output type, and phase in the study (see Table 2). Examining how frequently the giraffes interacted with the devices, one finds that the total number of interactions fell significantly between the baseline and the post-exposure condition for both systems (P = .021 for the proximity-based one and .001 for the touch-based one), as Figure 6 and tables 1 and 2 attest. That is, relative, to when the devices were not yet audio-interactive, the giraffes' interaction with them declined once audio had been introduced, and its frequency fell significantly after that, once the system was no

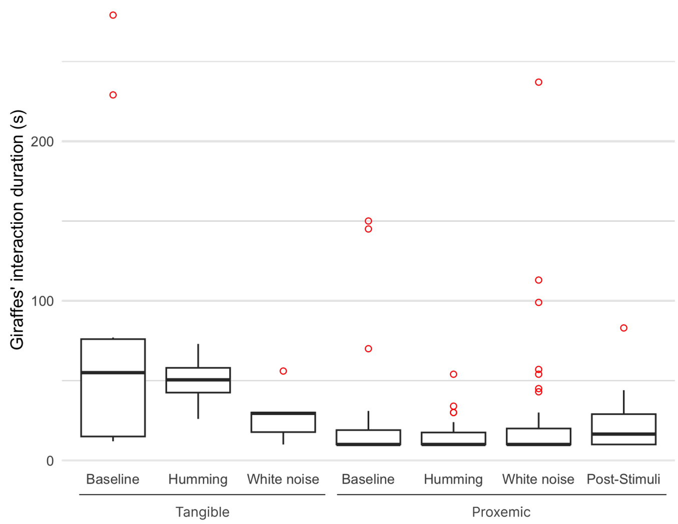


Fig. 7. Interaction duration (not normalised by study hours), by condition. No post-audio-condition bar plot is presented for the touch-based device, since no interactions occurred.

longer playing audio material. This result indicates that white noise and giraffe humming were unsuitable at least for the tower of giraffes studied.

Accordingly, our answer to RQ2 is that the giraffes showed no preference between the audio types – both devices were triggered more when they were silent, before and after audio had been used. It could be a possibility that the giraffes were somewhat interested in the devices at the outset and then grew bored.

8.2 Giraffes' Preferred Interaction Mode (RQ1)

Our statistical analysis of touching vs. proximity devices as a mode of interaction is summarised in Figure 6. As the figure clarifies, the proximity-based device showed a higher interaction frequency throughout than the touch-based device. As for the mean duration per interaction, the giraffes' use of the touch-based one typically lasted between 1.6s - 22.7s, while the proximity-based device's corresponding range was 1.6s - 8.4s (see Table 2). The overall non-normalised mean interaction duration across all conditions for the touch-based device (M = 34s) was clearly higher than that for the proximity-based device (M = 24s) (see Figure 7). A clear contrast emerged: when use is measured by frequency of interactions, the proximity-based device saw significantly more use than the touch-based one (P = .0006).

In summary, there were more interactions with the proximity-based device than the touch-based device; however, engagement with the touch-based one when it did get triggered lasted longer. These results responding to RQ1 demonstrate that the modality of an audio system influences giraffes' interactions.

8.3 Zookeeper Feedback

The keepers on duty were asked to provide estimates throughout the study as to what percentage of time the tower spent displaying stereotypies. We requested them to watch for five specific boredom-indicating behaviours that members of the group had a history of exhibiting (object-licking, non-specific licking, tongue-rolling and similar 'playing' with the tongue, cribbing/wind-sucking, and pacing) [3]. The keepers reported no difference in the occurrence of these repetitive compulsive actions between any of the three phases of the study. This finding implies that neither system provided enough enrichment to decrease boredom-linked behaviours. The head keeper of the giraffes when asked about the system commented that "the most interest was shown [by the giraffes] during the initial control stage, and tapered off". Speculating on the results, they comment that this "may indicate that the giraffes were more interested in the novel object rather than the humming. The longer it was hanging up the least interest they showed in it".

9 DISCUSSION

Both the study's results and the design process for the two systems offer important lessons. We discuss these implications below, then present recommendations related to the mode of triggering a system with specific reference to giraffes' interactions with technology (RQ1) and the suitability of audio stimuli for zoo-housed giraffes (RQ2).

9.1 Reflections on Modality and Audio Preferences

The fact that the study's giraffes did not favour any specific type of audio and, furthermore, decreased their interaction with both devices after they began to play audio echoes similar findings from zoo systems' introduction of audio devices with orangutans. Namely, when Pons et al. [37] introduced a ball modified to provide audio interaction, the animals learned to avoid it. The giraffes' continued avoidance of the systems once the audio responses stopped represents a long-lasting effect. This persisting lack of interest strongly suggests that giraffes prefer silence. It and corresponding findings in the orangutan study call attention to the potential for altered interactivity of an object (e.g., extending a spherical cage's touch-based response) to affect animals' interaction with their environment long after a return to non-interactive items.Future work could look at how long the effect persists and how similar the items must be to the noisy ones in order to suffer this effect.

Implication 1: Giraffes' apparent preference for silence over the audio stimuli studied (giraffe humming and white noise) points to a need for examining other sorts of audio and/or use of non-audio enrichment.

Secondly, the mode-specific results suggest greater interactivity inspired by proximity-based triggering, in that the interaction frequency was significantly greater than in the touch-based setting.

This could be due to the former's larger 'catchment area': the physical activation zone was larger than that of direct nudging or headbutting, and it covered various behaviours, from walking slowly past to get to the nearby feeding basket to pacing back and forth in front of the device. The finding draws attention to the technology-use effects of how often – intentional and inadvertent – system-triggering behaviours occur in the enclosure.

Implication 2: Triggering the proximity-based device significantly more than the touch-based device but interacting longer with the latter suggests that researchers should examine the influence of activation thresholds on behaviour, coupled with whether triggering is genuinely chosen.

Changing a system by introducing new interactive features complicate the animal's understanding of the device's functionality [16]. This is a perennial challenge in zoo computing contexts [8, 14]. Computer systems should express their functionality clearly, which includes pairing the responses with a specific input behaviour. While the concept of intentionality in connection with animals' interactions is subject to debate among ACI scholars, with some maintaining that it is impossible to measure an animal's intentions [19] while others have reached exactly the opposite conclusion [13], there is abundant evidence that animals possess some awareness of cause–effect relations, at whatever level.

Reflecting on our system for seemingly neophobic animals emphasises the flipside, however. While more direct triggering (e.g., by touch) might better capture intentional interaction, in that it requires a specific behaviour, the interactivity ends up impaired since such a system is less discoverable. To uncover the stimulus–response relationship, giraffes have to exhibit the behaviour sought.

Our case offered a lesson on interactivity and affordances: since the giraffes explored the systems more in the beginning, we recommend either having the system be fully functional from the start, to capitalise on the early, exploration-rich stage, or easing introduction via mid-study switching to a form of audio that the giraffes find definitely stimulating. More nuanced/granular measurement of space use in the enclosure could provide considerable knowledge of the animals' relations to the area before, during, and after the device's availability there.

Creating systems for long-term use poses a further challenge. Continued exposure can blunt the effects and lead to unresponsiveness. This phenomenon, referred to as habituation, reflects growing accustomed to the stimuli or objects to which one is exposed whether white noise or car alarms [50]. After the habituation period, reduced novelty may well cause the user to lose interest. That is precisely the pattern we observed with the touch-based device. Recording zero interactions after 168 hours of exposure attests that the system had a short 'life span'. As the zoo's head keeper of large mammals reflected, 'lots of interest was shown during the initial control stage', which 'may indicate the giraffes were interested in the novel object rather than the audio stimuli'. Because novelty effects are not confined to non-human animals, we can draw lessons from HCI findings; for instance, Balestrini et al. [1] identified a tension inherent to creating technologies that simultaneously are novel, are interesting, and receive sustained usage. In light of these issues, a study similar to ours but over a shorter time span or adding of new features as habituation sets in might be beneficial. Still, since captive giraffes are recognised as neophobic, which is defined as the fear of anything new [43]. If humans are to accurate measurement of changes in their use behaviour might require the humans who perform the measuring to let the animals interact with the devices and identify their affordances over a longer time. In this respect too, a balance must be struck. Giraffe computing demands both creating a device that clearly reveals its functionality and maintaining interest in it, for sustainable use over time.

Implication 3: Computer-based audio systems targeted for giraffes should present their interactivity from the outset, with a balance of discoverability and awareness of intention factors.

The shortcomings of human-centred measurement for animals remind us of the complexity of what it means for giraffes to interact with computer systems. Animals' perceptions of computers cannot be fully known, so we confine ourselves to speaking of 'preferences'. This term nicely denotes a higher interaction frequency or longer engagement with a stimulus [17], but 'preference' does suggest that the animal enjoys interacting with the system in question and therefore uses it more. Ritvo and Allison [38] have argued that an animal's usage of a system does not necessarily imply enjoying it: the actions we regard as manifesting a preference could be driven by fear, instinct, reinforcement from external variables, and other such forces. This relationship is especially tenuous when devices are repurposed, as in our case. Even though it is normally safe to assume that a seemingly preferred interface adds quality to and enriches the animal's life, enrichment itself should be problematised. The response provoked is not always one of pleasure: an enriching device can produce a mild sense of fear or trigger instinctual behaviour in a way that does not harm the animal's welfare [49]. When we apply multifaceted concepts such as preference and meaning, we must remember that we work within the boundaries of what we (with our limited understanding as humans) know about how animals experience computers.

One crucial piece in the meaning puzzle is the paucity of research into the intentions behind the material captured in giraffe audio recordings and the information conveyed. For instance, it is distinctly possible that the audio equipment or media did not faithfully record the full range of frequencies at which giraffes communicate. When we discussed our results with Baotic, he stated that wild female giraffes had reacted to playback of these humming sounds, not only being 'able to recognise these are giraffe humming' but also being 'very curious and initially curious'. If low-frequency vibrations were muted in **our** playback, such that they were not readily perceptible [3] the animals might never have experienced the samples as 'real'.

That could have contributed to lack of interest. On the other hand, reality-related elements may have had the same effect. The recordings came from another tower so might have aroused little interest in any case. Likewise, a phenomenon akin to cows' regional accents[4] could have been at play. Giraffes might recognise regional dialects or intra-group auditory constructions. Unknowns of such types are omnipresent in research involving animals' audio enrichment. Even in humans, factors of this nature are subjective and hard to articulate.

9.2 Lessons for Designing Interactive Systems for Giraffes

Since ours was the first computer device built for giraffes, we followed a general process developed by HCI scholars for user-centred design, which involves gathering user requirements and testing viable interfaces in aims of identifying suitable interaction methods [32]. Developing the interactive system brought the challenge of identifying a good input mode in light of giraffes' everyday behaviours. One manifestation of this issue arose during prototyping for the touch-based device. The force distribution characterising nudging of the device with the head, tongue, or neck proved to be bimodal, reflecting two typical interactions: a strong headbutt or forceful swing of the neck and a series of small nudges and/or licks. While our system registered these inputs as the same, the two behaviours could be treated as distinct. For example, a system might register the latter as expressions of curiosity and respond accordingly.

This example points to the larger question of what computer input for giraffes should resemble. In employing iterative discovery of affordances in a selection of gestures, we followed a pattern similar to HCI development [15, 32]. Transferring this template might not be appropriate, however: For example, human designers cannot readily gauge interference effects from prior iterations. Also, exploratory design can produce stress in nervous zoo animals, certain species, etc. Giraffes display the instincts of prey animals – they are skittish around unfamiliar people and items such as computer equipment new to them [43]. We pinpointed a solid way forward for addressing such concerns. The ethnographic approach sensitised us to ways of reducing negative behaviours in our case-specific development context [31]. Therefore, we recommend ethnographic observation before physical prototyping. Furthermore, devoting considerable time to observing the animals and to introducing the zoo-toy prototypes led to the giraffes displaying fewer signs of nervousness around the researchers and the computer equipment. Repeated visits to the giraffe enclosure verified these benefits.

Implication 4: For the early stages of the process of designing for giraffes, we recommend conducting ethnographic observations before physical prototyping.

[3]giraffes perceive sound via their ears, and some authors speculate that low-frequency vibrations perceived through their frontal sinuses and feet are handled similarly to elephants' infrasonic 'rumbles' [2]
[4] See the BBC news summary at http://news.bbc.co.uk/2/hi/5277090.stm, 'Cows also "have regional accents"', accessed on 9 September 2022.

9.3 Reflections on Where HCI and ACI Meet

As researchers explore the intersections between computers and animals, across a range of domains, reflecting on the methods transposed from HCI and applied to animals is essential [53]. While our study took HCI-rooted requirement-gathering, prototyping, and testing methods as a starting point, we recognised a need to tune them for a non-standard, animal-involved context. We aimed to shape our technology for user needs and requirements by synthesising information from zoos (keeper questionnaires, interviews, and the literature), what we observed ethnographically, and quantitative evaluation of the animals' interaction-related behaviours.

Such sensitivity notwithstanding, designers' limited window on how a giraffe – or, indeed, any user – perceives the world can render it tricky to create appropriate systems [46]. Creating technology in reduced-knowledge situations is plagued by ethics questions related to how users (people and animals alike) should access technology if we cannot fully measure the impact on their psychological, social, and physical health [42]. While informed consent is available as a risk-mitigation mechanism and barometer in human-research settings, such concerns still remain, in that humans may have insufficient capacity for it [26]. Alternative safeguards are available in these situations; for example, when technologies are introduced to children and people with impairments that reduce their capacity of understanding, other people, such as parents/guardians, can act on their behalf [26]. This is the route we followed in paying close attention to the zookeepers as guardians of the giraffes' welfare. Though such bridging might still leave a gap, it clearly enhanced development of the giraffe technology.

Our work paralleled HCI efforts also in considering users' role in creating technology. Research attests well that assigning passive roles (such as end user or tester) to people who typically hold little power in design situations (such as children) leaves the project's leaders viewing themselves rather than the users as the experts [26]. With our methods, we aimed to create space for animals to form their own experiences as agents in their own life. Reflecting on lessons from our attempt to consider them equals in the process, we would advocate zookeepers adopting the same mindset. Although designing computers for animals relies heavily on human choices, about aesthetics, stimuli, modality, and other factors [15], seeking ways to involve animals can cultivate more equal footing.

Our field's strivings for ethical, inclusive design alongside users can benefit from the HCI discipline's deep roots. Positing that all computer interactions are interconnected delineations, we propose dialogue between the human–computer and animal–computer interaction fields. By sharing the challenges and findings rather than viewing HCI and ACI as disjoint fields, we can acknowledge all the worlds experienced, whichever self is at the centre of them. This vantage point highlights the diversity that enables us to view, create, and measure technologies for others well.

10 FUTURE WORK

While this study represents a significant step forward in the development of technologies for zoo-housed giraffes, it was set within specific deployment conditions. Firstly, the opinions expressed in design discussions, the enclosure environment, the resources available, and the zoo involved all affected how the study was designed and conducted. The giraffes themselves constituted another factor. This was an all-female hybrid tower, and these were five specific animals. Other giraffes, in other configurations (mixtures of sex, age, breed, life experience, and relationships) could yield different results. All of these factors speak to the need for replication to validate our findings and permit generalisation to other populations. Future work could address generalisability with specific regard to the audio stimuli chosen, for instance. Testing recordings of low-frequency communication by more familiar giraffes (from animals of the same species or even the very giraffes under study) with such a system would enrich the findings. Furthermore, it could uncover vital implications for audio-based enrichment work with species that communicate similarly to giraffes, such as elephants, or even more broadly.

Regarding technology, we found the main limitation to be the lack of a constant power supply to the touch-based system. In combination, the need to remove the device for charging and the keepers' shift-based rotation resulted in occasional forgetting to hang the system back on its support. While our logging faithfully tracked when the device was actually attached, steady availability of electrical power would improve reliability and consistency, thereby making future systems more sustainable in several respects. Our post-project musings highlighted, in addition, another possible interaction mode for such technology. This is related to zoo-based giraffes' frequent licking of their enclosure, especially branches. For the next step in our work, we plan to build systems that redirect this stereotypy, thereby taking advantage of the key role of giraffes' tongue in interaction with the environment. This should advance our laying of groundwork for giraffe–computer interaction. Likewise, we have an objective of holistically exploring the spectrum of system-output mechanisms, such as visual, olfactory, and tactile stimuli, to find out how computers can enrich a giraffe's life in captivity.

11 THE OVERALL CONCLUSION

Our study contributed to developing species-sensitive computer enrichment (via a focus on giraffes) and to scholarship examining modality (with particular attention to touch- and proximity-triggered audio playback). The process of developing prototypes that allowed the giraffes to play giraffe humming or white noise by touching or standing in front of the system 1) informs understanding of how giraffes and other users could engage with audio interfaces but also 2) illustrates a sensitive design process of gathering requirements, consulting with keepers, conducting ethnographic research, and testing various interfaces. Our mode-related findings from two months of implementation with the zoo's five-giraffe tower – namely, that giraffes seemed to prefer the devices in their non-interactive (i.e., silent) state and that the proximity-based mechanism prompted more frequent triggering but less intense interaction – point to the possibility that the interaction mode could influence a giraffe's interaction with a computer-based device. Furthermore, the design process promoted awareness of issues connected with design for giraffes while also offering more general lessons. Woven throughout our research were considerations of whether we can transfer knowledge from HCI to ACI and, if so, what issues need to be addressed and which strategies suit both approaches. Scholars and practitioners could learn from our reflections on design-process similarities between the HCI and ACI domains. Our recommendations addressing ethics implications and the role of the animal as a user hold relevance for both disciplines and, hence, the rich juncture between them.

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