CreatureConnect: Exploring Shared Control of Multimodal Interaction by Humans and Lemurs

Jiaqi Wang
University of Glasgow
Glasgow, UK
2798509w@student.gla.ac.uk

Stephen Brewster
University of Glasgow
Glasgow, UK
stephen.brewster@glasgow.ac.uk

Ilyena Hirskyj-Douglas
University of Glasgow
Glasgow, UK
ilyena.hirskyj-douglas@glasgow.ac.uk

Figure 1: At left, a lemur engages with *CreatureConnect* within the enclosure. On the right, children use the system in tandem with lemurs.

ABSTRACT

While zoos deploy technologies for animals' enrichment and visitors' education, little research has investigated how technology can support joint computer use by animals and people working together. To bridge this gap, we developed CreatureConnect, a distributed device with which lemurs and zoo visitors alike can control the intensity of sounds, smells, and visuals on either side of the enclosure boundary. Over 20 days of subsequent observation, we recorded 541 lemur-system interactions, observed 16,139 zoo visitors, and collected 696 sets of questionnaire responses to examine the effects of distributing control on both species across baseline, visitor-control-only, lemur-control-only, shared-control, and no-control conditions. While lemurs used CreatureConnect significantly less when controlling it alone, humans exhibited significantly greater engagement, education, empathy, and overall-experience value under shared-control conditions, which outperformed all other conditions. In light of the results and the fundamental role of interaction and interfaces in animal–computer and human–computer interaction, the paper examines its vital implications for between-species collaboration and control.

CCS CONCEPTS

• **Human-centered computing → Interactive systems and tools**.

KEYWORDS

animal–computer interaction, animal–visitor interactions, shared control, choice and control, multimodal systems, red-ruffed lemurs, zoo visitors

ACM Reference Format:
Jiaqi Wang, Stephen Brewster, and Ilyena Hirskyj-Douglas. 2026. CreatureConnect: Exploring Shared Control of Multimodal Interaction by Humans and Lemurs. In *Proceedings of the 2026 CHI Conference on Human Factors in Computing Systems (CHI '26), April 13–17, 2026, Barcelona, Spain.* ACM, New York, NY, USA, 23 pages. https://doi.org/10.1145/3772318.3790643

1 INTRODUCTION

Many zoos and aquaria offer visitors direct contact with animals, with petting, walking, swimming, riding, and feeding encounters supplying what scholars call animal–visitor interactions (AVIs) [86]. Though these activities are intended to educate visitors, increase their knowledge of wildlife conservation, and support global conservation efforts [2, 27, 29, 81, 86, 95], research suggests that most AVIs compromise animal welfare and conservation, despite positive ratings by humans. In addition to the gulf between positive experiences for visitors and negative ones for animals [86], AVIs expand the transmission of zoonotic diseases and the risks of injury to both animals and visitors [32, 34]. Yet, with more than 700 million visits to zoos a year [51, 87], demand for AVIs continues to rise

---

CHI '26, April 13–17, 2026, Barcelona, Spain

ACM ISBN 979-8-4007-2278-3/2026/04
https://doi.org/10.1145/3772318.3790643

[27]. Noting the associated renewed concern about animal-welfare impacts, the UK government has ramped up its introduction of regulation aimed at minimising human interactions with certain captive species [122].

In response, researchers have begun to explore how digital technologies can mediate AVIs. Studies attest that visitors who can view or experience the same technology as animals exhibit stronger empathy, engagement, and education [127, 129]. For the animals, such systems offer valuable enrichment by supporting species-specific competencies and targeting the cognitive and physical processes used by their wild counterparts [25]. However, most current technologies still address either animals or visitors exclusively [64, 78]. This restricts opportunities for genuinely mutual interaction. While Yamanashi et al. [135] demonstrated that animals and people can operate the same system, little is known about how control is best distributed between species, not to mention how particular allocations affect either. Vital questions arise about balancing agency between animals and visitors in AVI systems' design.

An animal's capacity for agency – that is, choice and control over its own life – correlates with better welfare [14]. Hence, agency has emerged as a central pillar of the animal–computer interaction (ACI) discipline [79] and a key theme for the animal-cognition community [15]. While ACI scholars recognise agency as empowering animals to use technologies independently and make meaningful choices over fundamental aspects of their life [25, 131], implementing choice and control presents complex, multifaceted challenges [31]. One evident factor is that choosing is an inherently rewarding and intrinsically motivated behaviour [31, 138]: while animals cannot say so directly, research strongly suggests that they enjoy making choices in itself [31]. In fact, choice is so powerful that animals undertaking a computer-based task often pick options with less preferable outcomes (e.g., smaller rewards) if these end up giving them more choices [138]. Also, animals value a non-binary approach; they typically prefer having more than two options, even when consistently selecting the same option [31]. In any case, if animals are to benefit from agency-based approaches, a perceived 'internal locus of causality' (or control) must motivate their use of technology to control the environment [15]. This factor further complicates implementing animals' control and choice in human-managed settings. For instance, humans at zoos may want to exert control/choice via a shared AVI system. This leads to questions about designing technologies that offer both parties meaningful choice and control, alongside how the approach to agency affects animals and visitors.

To explore choice and control in technology-mediated AVIs at zoos, we developed *CreatureConnect*, a dual-device system that delivers random combinations of bimodal visual, olfactory, and auditory stimuli in real time to a device for red-ruffed lemurs and a device for human visitors. We then tested this system by varying the control over stimulus intensity in four conditions: visitor-only control, lemur-only control, shared control, and 'no control' (control by the device without user input). Visitors adjusted intensity via a touchscreen slider while lemurs did so by means of proximity, with coming closer producing higher values. In single-party control conditions, the system fixed the intensity of the other modality at a medium level, whereas the system's no-control condition randomised the intensity without input from either side. In all four conditions, each device presented both stimuli simultaneously to support joint use irrespective of control. The system was deployed at our partner institution, Blair Drummond Safari Park, where it was used by five lemurs and roughly 16,000 visitors over 20 days. The system recorded the lemurs' and visitors' interactions with their respective devices throughout the study. For further information on the impact on visitors, we measured their engagement at the lemur enclosure (frequency and duration of visit) and employed a questionnaire to collect data on education effects, empathy, and the overall experience. Thus, the study addressed two central questions:

RQ1: How does lemur and visitor interaction with *CreatureConnect* reflect the environment control afforded: lemur-only, visitor-only, shared, or none?
RQ2: How does *CreatureConnect* affect visitors' engagement, education, empathy, and overall zoo experience?

Examining the 541 lemur interactions identified and the visitors' engagement with the technology revealed that control significantly affected the time lemurs spent near their *CreatureConnect* device. The interaction patterns' dependence on control level led us to deduce that lemurs can exercise self-directed control via computer systems. In combination with evidence that choice opportunities and control over environmental functions improve animals' welfare [69], these findings suggest that *CreatureConnect* could enhance well-being among lemurs by offering them meaningful opportunities for control. From 1,719 visitor–technology interactions and 696 questionnaire forms, we found that visitor engagement, self-reported education, empathy, and experience scores were all greater with the technology than in its absence, reaching their highest levels in the shared-control condition. These indications that AVIs can significantly enrich visitor experiences point to the importance of further questions about control dynamics, mutual perceptions between animals and visitors, and how varying the control factors shapes agency.

Core contributions: Human–computer interaction (HCI) scholars define interaction as 'mutual or reciprocal action or influence' [50]. Building on their exploration of the more-than-human landscape, this paper extends the definition to encompass experience and meaning-making across species boundaries. Our methods, hardware, and software implementations, which enable dynamic exchanges between animals and humans, demonstrate reciprocal influence and shared engagement. This contribution, inspired by prior work showing how technology can offer support across the enclosure boundary, might well represent the first investigation of control and means of its technology-mediated sharing via multispecies AVIs in zoo settings. By framing animals not as objects of education but as co-stakeholders and co-controllers in visitors' learning processes, its approach offers a more inclusive basis for designing educational technologies. Our findings challenge certain prevailing assumptions in ACI and animal-behaviour/cognition work – namely, that animals having more control over their life automatically enhances their welfare and that animals choose accordingly [14, 31, 72]. From our new theoretical vantage point, the relations among choice, control, and animal welfare prove far more nuanced than previously thought.

2 BACKGROUND FROM THE LITERATURE

Zoos play a vital role in wildlife conservation, yet captivity inevitably constrains some aspects of animal welfare [14, 102]. To mitigate associated challenges, ACI researchers have introduced technology-based enrichment in zoos, applying user-centred design principles adapted from HCI [17, 44, 76]. Below, we review work on multimodal animal technologies and technology-mediated AVIs, alongside how the control assigned and the choice provided mould both.

2.1 Multimodal Technologies for Captive Animals

Kleinberger et al. [65] offered a starting point with an 800-study review finding that zoo technologies primarily consist of screen- and audio-based systems involving interactive objects and wearable devices. Animal technologies typically apply visual (63.32%) and auditory (27.64%) modes. Though olfactory ones seldom feature (1.01%) [65], they are fundamental to animals' foraging behaviour and therefore warrant deeper investigation [104]. The review cites touchscreen video systems for orangutans, which increased the time spent in technology-equipped areas [106], and classical music for Asian elephants, which reduced stereotypy [133].

Three cue types are central to non-human primate welfare: visual, auditory, and olfactory [7, 132]. Visual cues are fundamental for these primates' social behaviour and foraging, and visual enrichment of their environment can reduce abnormal behaviour and foster appropriate interactions [104, 132]. For example, video augmentation expanded the space used by Japanese macaques and reduced maladaptive actions [89]. Auditory stimuli, in turn, are crucial for non-human primates‘ communication and threat detection (e.g., in alarm calls among tamarins and sifakas). Their elicitation of strong attentional responses lends support to widespread use of acoustic enrichment [64, 133]. Red-ruffed lemurs' foraging speaks to the value of olfaction [104], with studies of captive red-ruffed lemurs demonstrating that olfactory cues yield more engagement than visual or auditory stimuli [127]. Perhaps unsurprisingly, enrichment that combines several stimulus modes engages animals more effectively than unimodal stimuli do. For instance, multimodal combinations produced significantly stronger engagement than any one mode in the study of red-ruffed lemurs. This makes sense: every animal both perceives the world and communicates by multiple means [14].

2.2 Animal–Visitor Interaction in Zoo and Aquarium Settings

Zoos and aquaria not only support animal-welfare efforts but also provide key venues for public encounters with wildlife, thereby educating the public in species conservation, ecology, etc. [82, 130]. Through AVIs, untrained visitors can physically interact with captive animals in ways that are designed to be safe and potentially beneficial for both parties [27, 112].

AVIs sometimes can jointly serve animal welfare and visitor education [38, 56]. For example, walk-through ring-tailed lemur enclosures have increased the closeness perceived by visitors [38], and visitors' feeding of crowned lemurs has reduced their aggression relative to zookeeper-only feeding [56]. However, Spooner et al. found that high-intensity visitor contact and prolonged exposure can degrade animal welfare [113]. The waters get muddied further by generalisation across species. For instance, petting by humans does not change the behaviour of captive southern hairy-nosed wombats but can provoke biting among sea lions, which could bring physical harm to animals and visitors [49]. Given these mixed outcomes, the World Association of Zoos and Aquariums issued guidelines recognising AVIs' potential to benefit animals and visitors but specifying that animal welfare should take precedence [134]. In 2025, the UK government tightened its legal regulation of AVIs to prohibit touch-based interactions with fish and cephalopods in light of welfare concerns, underscoring growing awareness that safe, non-contact approaches are needed for 'wildlife first' AVIs [122].

Zoo-based AVIs frequently play a part in conservation education, yet they can have positive, neutral, or negative impacts. Also, most encounters remain non-technological [113] even though technology offers safe, non-contact alternatives that preserve AVIs' benefits while reducing risks to animals and visitors alike [23]. For instance, Melbourne Zoo's floor-projection system showcased cognitive and sensory enrichment for orangutans and added to visitor empathy from watching the animals play [129]. After that came Yamanashi et al. [135] system, which enabled chimpanzees and humans to control a projection device through motion-tracking buoys on each side of the barrier. They reported no negative effects on chimpanzee behaviour while observing that the animals spent more time in the deployment area when the system was made available than in the control condition, when it was not [135]. Encouraged by these results, Wang et al.'s multimodal device for lemurs [127], which visitors could see while engaging with a similar device that let them directly experience the same stimuli. The animals took up this AVI technology, and it simultaneously improved zoo-visitor education, empathy, and experience ratings. In other work, Martin et al., who designed three abstract competitive tasks for chimpanzees and humans' joint play via a touchscreen, found that chimpanzee choices closely matched game-theoretic equilibrium predictions – and were even more optimal than human choices [77]. Notwithstanding such clear evidence that AVIs can benefit animals and visitors, and that animals can apply technology for social tasks and cognitive enrichment, scholars have only scratched the surface of how animals and zoo visitors might share control of the same technology, let alone the complexities of how control gets allocated across species and the effects on both sides of the interaction.

2.3 Control and Choice

One way zoos improve animals' living and welfare is by according them agency through opportunities for choice and control [14, 25]. Our discussion of this applies Browning et al.'s definitions, under which *agency* is an animal's capacity to make choices and control its environment in line with individual-specific needs [14], *choice* entails selecting between/among alternatives, and *control* refers to influencing outcomes through one's behaviour [15, 31, 68]. Enrichment-focused technologies at zoos should empower animals to control stimuli themselves rather than rely on human operators, and they should be offered the ability to exercise choice through multiple options [25]. Mechanisms aligned with these principles act against stress and learned helplessness [11, 14, 25, 137]. Also, for control to hold meaning, the animals must perceive the 'locus of control' [4, 15] as internal, not external: they must recognise their actions' influence on events and on their life. This perception is so powerful in animals that, for instance, common marmosets repeatedly turn enclosure lights on and off for the sake of control [15]. Interpreting control as internal has led to significant reduction in such negative indicators as pacing and scratching, alongside an increase in (positive) calm-locomotion behaviours, in comparison to not sensing control [3, 15, 93]. Animal behaviourists now commonly regard an animal's control over stimuli as mattering more than the actual stimuli do [3, 15]. A similar pattern is visible for choice; often, the availability of options proves more meaningful than the one selected [31, 138]. There is a clear commonality with the fundamental role of choice and control among humans: even illusory control can boost people's engagement and experience [68].

The parallel is especially visible in the strong effect of experienced agency on human interactions with technology [70]. In human-centred design, systems are built to support user choices and control, to enable shaping one's technology experiences through adaptation and personalisation crafted to maximise utility and minimise frustration [5]. Scholars of HCI have found that role imbalance and dependency can arise if the distribution of control between humans is not handled well [16]; likewise, human–machine shared control may cause confusion and weaken people's sense of agency [21]. These challenges notwithstanding, human–human shared control has shown an ability to increase enjoyment and engagement by fostering social identification and interactive communication (e.g., in social gaming [19]). Human–machine shared-control systems, in turn – from intelligent wheelchairs and semi-autonomous driving to AI-assisted art tools – have reduced cognitive load, improved system reliability, and stimulated user creativity [20, 21, 62, 115, 120].

When extending shared-control paradigms to zoos, we faced the question of how human and non-human users alike can exercise control such that a mutual system fosters agency and a demonstrably positive user experience for both. While studies with animal- or visitor-interaction devices have made some forays into cross-species technology use, we found none investigating ways of concurrently distributing control of these interactive systems between animals and humans, let alone how such balances affect either party. To fill the gap, we devised a dual-interface system whereby red-ruffed lemurs and zoo visitors can interact with each other, then examined how varying the assignment of control over the technology affects both users' interactions (RQ1) and zoo visitors' engagement, education, empathy, and overall experience (RQ2).

3 DESIGNING THE *CREATURECONNECT* SYSTEM

The two similar devices in the system, referred to as *CreatureConnect*, were positioned for physical visibility to both sets of users. In light of evidence that visitors gain greater educational benefits when able to see animals interacting with technology [127, 130], and also since such placement might also enrich the animals' experience, we installed them on either side of a glass viewing window of the lemur enclosure (see Fig. 1). The devices communicated with each other via the safari park's Wi-Fi network. Below, we outline the system's design rationale, material choices, interaction mechanisms, component configuration, choice of stimuli, and interfaces (for human and animal users).

The interaction mechanism: Agency and autonomy were central ethical considerations throughout the study. Development of the interaction mechanism began with observing how lemurs in the relevant enclosure behave. We found that their locomotion and positioning employ primarily relaxed hand postures rather than fine motor manipulation. This ruled out complex interaction mechanisms such as finger-presses or touchscreen interfaces. Also, we saw no evidence of tool use, so we excluded tools, such as a stylus, as employed with other primates [63]. We opted not to follow the path of developing species-specific bespoke buttons, partly because monkeys in past studies did not reliably operate these as triggers [61]. Instead, we chose to work with lemurs' natural spatial relations. In particular, the tendency to approach stimuli [108] has shown success as an interaction mechanism for monkeys [45] and specifically with lemurs [60]. Evidence that voluntary participation enhances non-human primate engagement [33] further supported designing a proximity-based control interface: lemurs could use the device as desired or avoid the interaction area.

To create the area, we used three infrared sensors mounted 30 cm above the device base, spaced 10 cm apart to match the average shoulder width of the lemurs. In our design, control was defined as modulating stimulus intensity. We mapped sensor readings to three intensity ranges for red-ruffed lemurs: high (4–29 cm), medium (30–54 cm), and low (55–80 cm), derived from testing with the animals and from consulting zookeepers to be sure the lemurs could switch distinctly between levels and engage only when approaching the device. For visitor' intensity changes, we chose a traditional touchscreen with a horizontal slider displayed.

Interaction logic: The design allows both lemurs and human visitors to activate and deactivate the interface, with visitors doing so by tapping the screen and lemurs by approaching or leaving the interaction area (as shown in Fig. 2). Our design choices ensured that the system can be used whenever a lemur or human visitor is present and treats the two as equal stakeholders. Permitting activation by either party facilitates genuine shared control, as does letting a user keep interacting after the other disengages. This respects user autonomy and choice by letting either party disengage at any time. In our setting, when a lemur left the interaction area, the interface was deactivated, unless a visitor remained. After 10 seconds elapsed without a visitor interacting, a prompt popped up, asking whether the user wished to continue. If no confirmation followed and no lemur was present, both interfaces were deactivated. As for activation, once triggered, the device presented each stimulus for 20 seconds (in a loop in the case of auditory or visual cues), continuing until interaction had ceased. We based this choice of span on evidence that lemurs typically interact with stimuli for six seconds [60].

Our context for stimulus control by both lemurs and zoo visitors was a bimodal combination of stimuli, with the modes (from the three available) and the content chosen by the system at the start of each interaction event. Randomising stimulus combinations across interactions ensured the most balanced representation possible across all experience conditions, even though this approach might

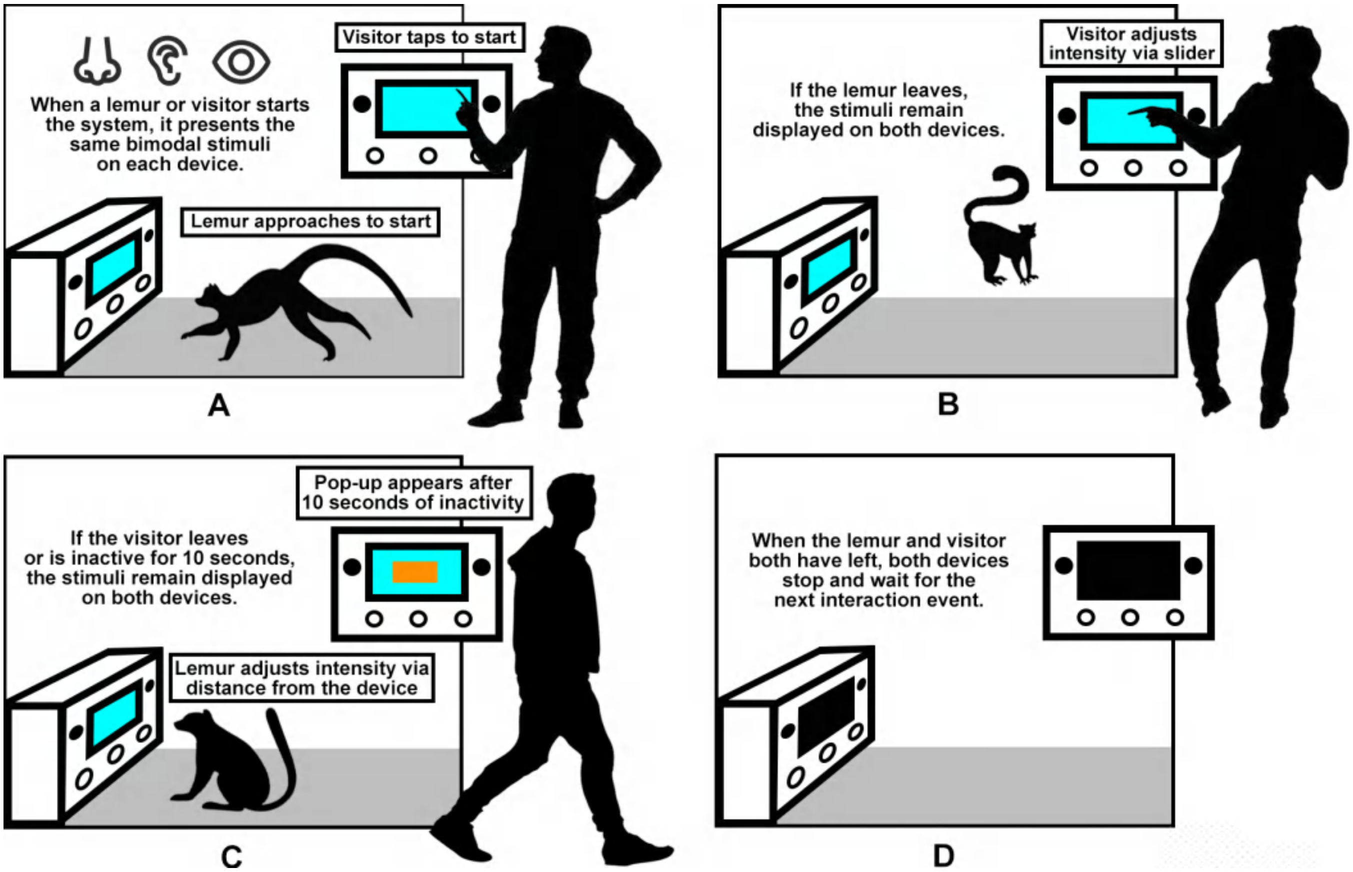


Figure 2: The interaction logic of *CreatureConnect*. A: When a lemur enters the interaction area or a visitor taps the start icon, the system activates, triggering a randomly chosen bimodal combination plus contents and presenting these synchronously via both user devices. B: If the lemur leaves while the visitor remains, the stimuli from both devices continue and the visitor may adjust intensity via the onscreen slider. C: If the lemur remains present while the visitor, after more than 10 seconds of inactivity, either quits explicitly or does not reply to pop-up prompts, both devices’ stimuli continue. The lemur may change the intensity via distance-based control. D: When lemurs and zoo visitors both have disengaged, the two devices cease their action and wait for the next interaction event.

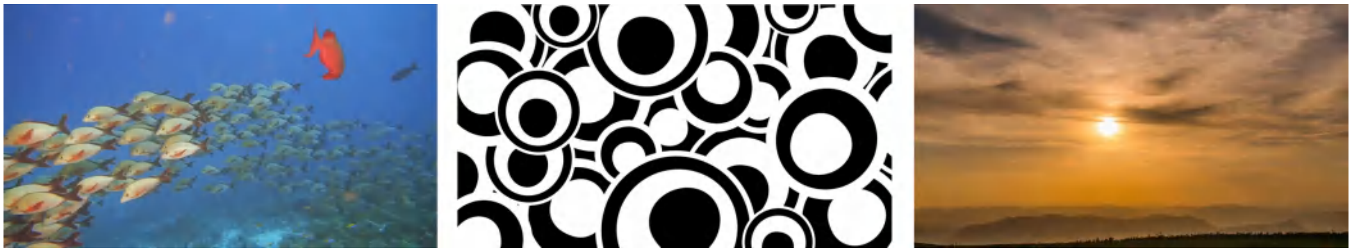


Figure 3: Screenshots from the video stimuli used in *CreatureConnect*: a school of fish (left), a black-and-white abstract pattern (centre), and a nature landscape at sunset (right).

influence participants’ sense of control, as discussed below. Limiting adjustability to the intensity of the stimuli, rather than also including control of their mode and/or content, reduces potential confounding between choice-making and control. Thus restricting the elements under lemurs’ control (to stimulus intensity, moderated via proximity to their device) provides for reliable and ethical measurement of control without reliance on trained abilities. The design assigns each stimulus channel to no more than one party; that is, each user adjusts only the intensity of the corresponding mode under the relevant control conditions: lemurs via proximity and visitors via the onscreen slider. *CreatureConnect* presents the two stimulus modes, the intensity of each, and their specific content in real time on both devices.

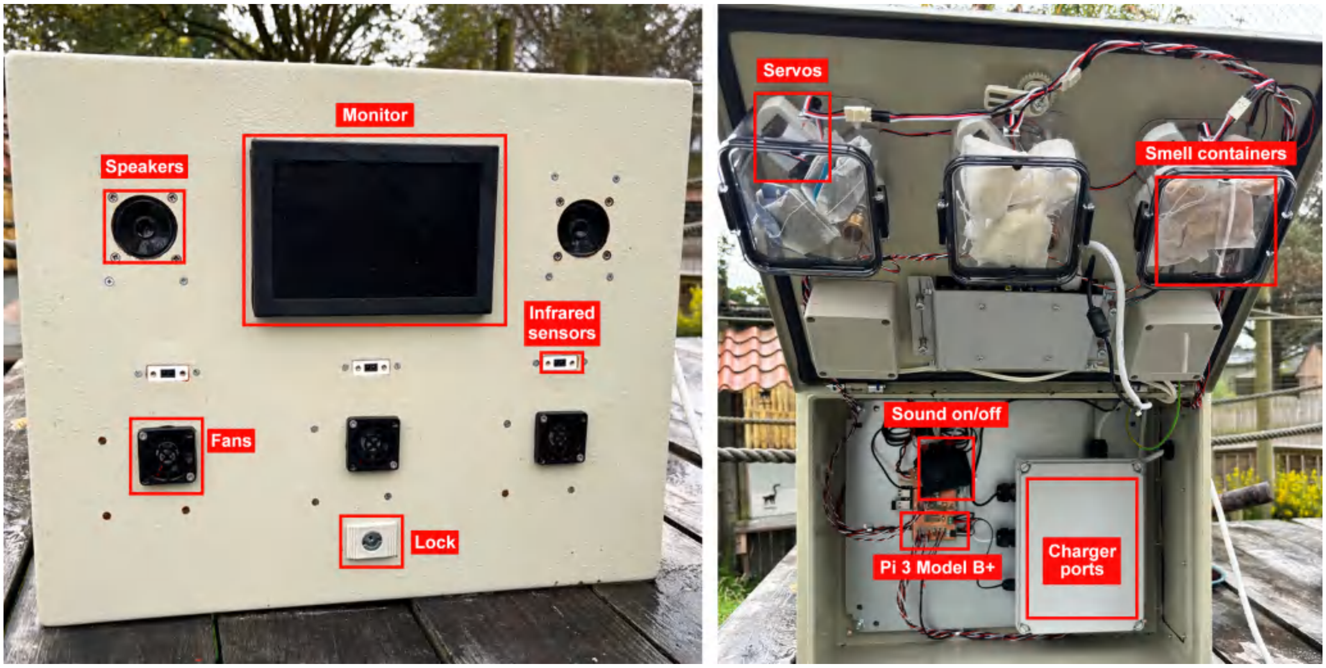
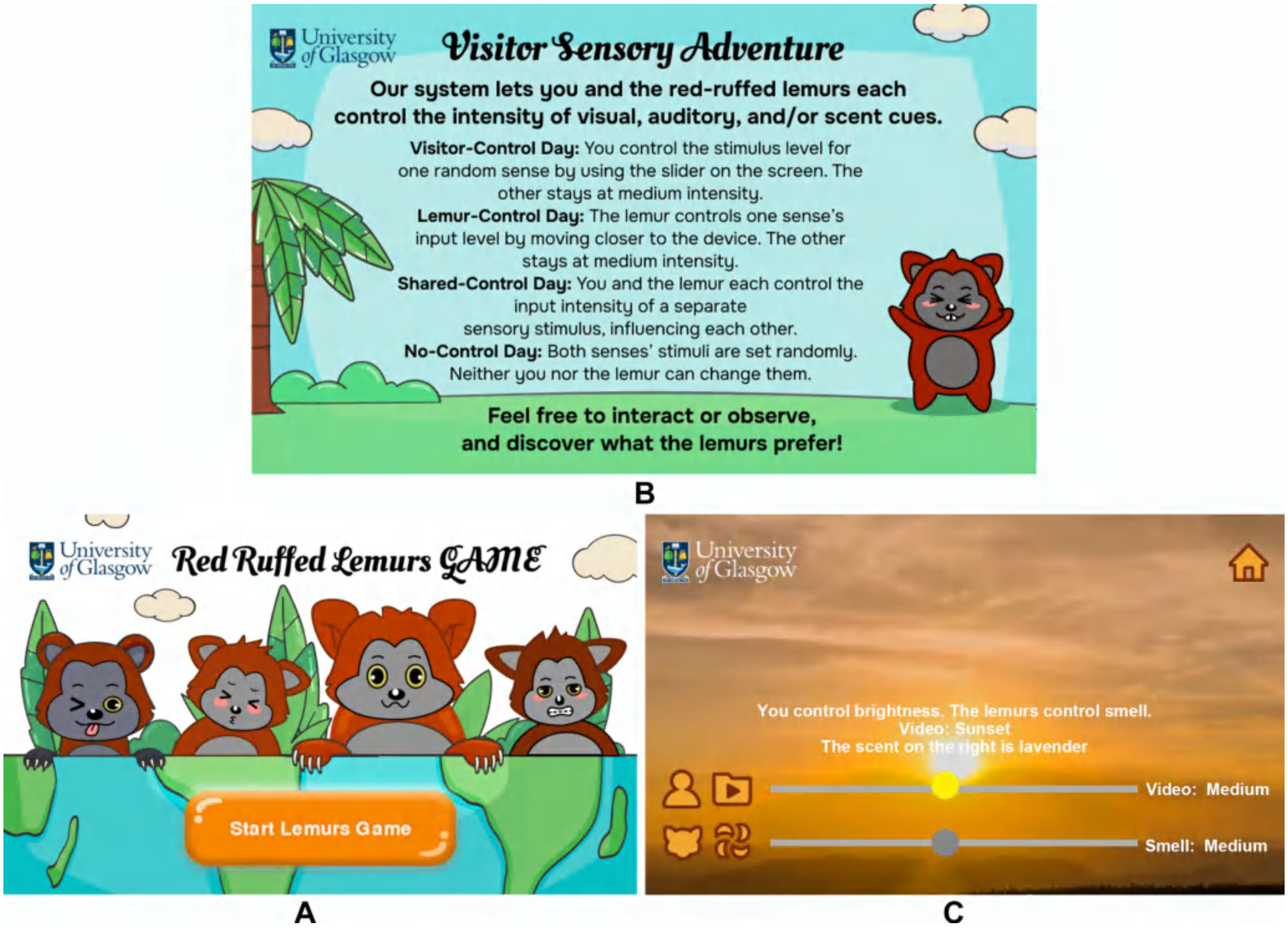


Figure 4: The structure of the red-ruffed lemurs' *CreatureConnect* device (exterior at left, internals at right).

Stimulus-intensity logic: In response to user input on intensity, the system modified screen brightness, audio volume, and the amount of scent-infused air emitted by each device. The brightness bands for the visual stimuli were 100–200 cd/m² for low intensity (25–50% of the 400 cd/m² maximum), 200–300 cd/m² for medium (51–75%), and 300–400 cd/m² for high (76–100%). For this species, in which brightness is a primary visual cue [126], these levels ensured detectable brightness differences without risking overstimulation [54, 126]. Corresponding sound levels were calibrated for audibility above enclosure noise and kept within ranges safe for humans and lemurs [121]: 55–65, 66–80, and 81–95 dB. Finally, lemurs rely heavily on their sense of smell, often using volatile chemicals to communicate (i.e., semiochemistry) [55]; however, grappling with scent intensity imposed several challenges [90, 136]. The commonplace parts-per-million (ppm) approach [58] does not suit concentrations of apple, mango, and lavender volatiles: weather variations preclude accurate measurement outdoors [136], and even in closed environments they typically extend from a few micrograms to dozens of milligrams per kilogram [18, 94, 125]. Human-based rating schemes, such as the Labelled Magnitude Scale (LMS), meanwhile do not suit cross-species contexts [41, 74]. Rather than resort to ppm or apply the LMS, we defined aroma intensity levels via a fan-speed modulation technique followed in prior work [12]: we increased scent-based air flow for low (25–40%), medium (41–70%), and high (71–100%) bands. This gave us a practical means of approximating olfactory intensity in outdoor settings.

The stimuli: Since our device accommodated only three odour sources, we selected three exemplars per mode. Firstly, to select the three olfactory stimuli, we conducted careful testing with the lemurs alongside a zookeeper since zoo-based smell research with non-human primates is quite limited. Seeking to confirm suitability and avoid offputting effects, we tested dried apple, jackfruit, sweet potato, coconut, pineapple, melon, and mango (studies show that lemurs prefer dried items to synthetic scents [127]) and also peppermint, lavender, vanilla, and osmanthus, in light of lemurs' diet favouring leaves (20.9% by weight), flowers (5.3%), and fruit (72.5%) [6, 42, 98, 124] and zookeeper suggestions. In addition, we tried cinnamon (a smell used in macaque scent-baiting [128]) and sandalwood. All sources were placed in mesh-covered containers, to which lemurs were exposed for five minutes (with gaps of two minutes, to avoid odour overlap). After measuring lemurs' engagement with the scents – by number of lemurs coming over to smell the items and in terms of interaction duration and frequency [99] – we selected apple, lavender, and mango for the olfactory stimuli. All five lemurs had engaged with these smells repeatedly (>5 times) and for sustained periods (>220 s per 5 min)

The choice of video stimuli paid special attention to colour and motion, which make a strong impact on non-human primates' engagement [8, 96]. Importantly, colour vision in red-ruffed lemurs is sexually dimorphic, with males being dichromatic and females trichromatic [71]. As our lemur participants were a mixed-sex group, we prioritised orange, yellow, and blue hues, selecting three videos with high-contrast motion and colour palettes (see Fig. 3): *Underwater Schools of Fish* (blue dominating, with orange fish; moderate speed) reflects preferences expressed by primates for fish content [46]; *Black-and-White Abstract* (high-contrast patterns; rapid motion) responds to red-ruffed lemurs' reliance on structural and luminance cues during foraging [13, 53]; and *Natural Landscapes* (orange–yellow sunsets; low speed) exploits evidence that natural scenes elicit sustained engagement in rhesus macaques [57].



Our system lets you and the red-ruffed lemurs each control the intensity of visual, auditory, and/or scent cues.

Visitor-Control Day: You control the stimulus level for one random sense by using the slider on the screen. The other stays at medium intensity.

Lemur-Control Day: The lemur controls one sense's input level by moving closer to the device. The other stays at medium intensity.

Shared-Control Day: You and the lemur each control the input intensity of a separate sensory stimulus, influencing each other.

No-Control Day: Both senses' stimuli are set randomly. Neither you nor the lemur can change them.

Feel free to interact or observe, and discover what the lemurs prefer!

You control brightness. The lemurs control smell.
Video: Sunset
The scent on the right is lavender

Figure 5: The visitor interface with the *CreatureConnect* system: Tapping the onscreen 'Start Lemurs Game' button pane A) causes the visitor device to display an introduction page (shown in pane B) and, after a few seconds, the control interface (illustrated in pane C). Along the sliders, intensity under visitor control is colour-coded to indicate the level selected – blue for low, yellow for medium, red for high – while non-adjustable levels are shown in grey. Explanatory text is presented above these. The lemur interface displays the same elements but without text and with the non-lemur-adjustable levels in grey.

As red-ruffed lemurs are most sensitive to sounds at 2–8 kHz [28, 36], we selected auditory stimuli consistent with this range and supported by enrichment effects found in studies of other non-human primates: *Rainforest Ambience* (irregular rhythm, 1–6 kHz, 40–60 BPM), commonly preferred by western lowland gorillas [93, 100]; *Electronic Pop* (steady rhythm, 0.2–8 kHz, 120–135 BPM), linked to high engagement levels in gorillas [118]; and *Lullabies* (steady rhythm, 0.2–3 kHz, 60–75 BPM), favoured by cotton-top tamarins and common marmosets [80]. For species-specific welfare checks, we piloted both the sounds and the video stimuli with the red-ruffed lemurs in the presence of a zookeeper. In a five-minute loop with each, no avoidance behaviours or stress reactions were observed.

Components – hardware and software: The lemur device utilises a monitor, speakers flanking the screen, and three motorised scent chambers with servo-controlled lids and ventilation fans housed in a waterproof box. This design was adopted to present stimuli at the lemur's body height, for optimal accessibility. Upon activation, the lids open and the fans disperse scents (through protective grilled vents, to guarantee safety for the lemurs). The components of the visitor device mirror the design of the lemurs' in all respects except that the olfactory system features no servo-controlled lids, since human olfactory sensitivity does not necessitate scent sealing. Both devices operate via Raspberry Pi controllers for synchronised interaction. Each interaction gets logged locally on the Pi and mirrored remotely on our servers. In addition to robust data collection, remote access enables maintenance with minimal on-site intervention. Finally, a camera opposite the lemur device records activity in the device's vicinity, supporting non-invasive monitoring of lemur–system interactions. Our system's code and hardware schematics are available via the University of Glasgow Enlighten Research Data repository (see https://doi.org/10.5525/gla.researchdata.2156) with Fig. 5 showing the onscreen display.

4 STUDYING CONTROL VIA THE IMPLEMENTATION: METHODS

The design of the 20-day field study implemented five conditions, the four technology conditions plus a baseline. We exposed participants to 1) the no-technology baseline, 2) visitor-only control, 3) lemur-only control, 4) shared control, and 5) no control, each for four days in all (two weekdays and two days at weekends, to balance the weekend increase in visits to Blair Drummond Safari Park). Four days per condition provided adequate observation data from animal behaviour while remaining resource-efficient [35, 103].

To control for order effects, the four technology-present conditions were counterbalanced over 16 days via a Latin square. The two devices were synchronised in real time across these four conditions, and data were collected from 11am to 4pm each day for guaranteed comparability across conditions [45, 93]. In both single-party-control conditions, the party granted control could adjust one of the two modes while the intensity for the second stimulus mode was fixed at medium level. In shared control, each party controlled a separate mode's intensity. On 'no-control' days, the system assigned intensities randomly, without user input.

To safeguard against negative effects, our methods incorporated several mitigation mechanisms. Firstly, zookeepers casually monitored the lemurs and notified us if they noticed any signs of stress or negative behaviours; none were observed during the study. Also, a primatologist carried out behaviour observations during half of the sessions (monitoring did not cover the entirety of all interactions) and reported no significant adverse responses.

We collected data from both lemur and visitor use of the system. The former included 1) device logs written to a local Raspberry Pi file capturing lemur–system interactions, which automatically recorded a timestamp, interaction duration, the stimulus mode and content, the triggering agent (lemur vs. visitor), and intensity, and 2) CCTV footage of animal–system interactions, capturing interaction frequency, duration, and the number of lemurs present simultaneously in the space where *CreatureConnect* was deployed. Interactions by human visitors were logged via their device in analogous format, to enable cross-validation. For privacy reasons, we did not expose visitors to cameras.

To assess human engagement, education, empathy, and experience, we examined visitor activity and questionnaire responses in combination. Over each five-hour stretch, we alternated between observation and questionnaire periods at one-hour intervals. The observation gauged engagement in terms of visitor numbers and time spent at the red-ruffed-lemur enclosure, while a researcher in a high-visibility vest handled the questionnaire component by inviting one member of each visitor party at the lemur enclosure – inclusive of children, upon a guardian's consent – to complete a survey and consent form (presented in the supplementary material) immediately after viewing the lemurs.

The questionnaire solicited data on demographics, visit frequency, education effects, empathy for the lemurs, and the overall experience with the *CreatureConnect* system. We assessed education effects by means of the Tunnicliffe Conversation Observation Record (TCOR), a validated metric for judging visitors' education at zoos by listening to their conversation topics [91, 119]. To preserve their privacy, the TCOR instrument was modified to ask visitors which topics they had spoken about, within nine domains (animal management, exhibit features, animals' behaviours, etc.). For evaluation of empathy, which plays a pivotal role in eliciting positive attitudes among visitors and protective behaviours oriented toward animals [114], we adapted Luebke's zoo-specific empathy questionnaire [73] to use 'smileyometers', a child-friendly technique that applies smiley faces to solicit Likert-scale responses from all visitors, from children to the elderly [123].

Semi-structured interviews with three lemur-keepers supplemented the data by probing their views of how the various control conditions influenced lemur behaviour, of visitors' impressions, of the visitor–lemur interactions, and of the system's future potential. The interview material allowed triangulation of data from lemurs, visitors, and lemur-sensitive professionals.

4.1 Terminology

For purposes of clear discussion of animals interacting with computers, this paper uses the term 'interaction' for a continuous event upon system activation when a lemur is identified within the system's tracking space while reserving 'preference' for lemurs' demonstration of significantly increased engagement frequency or duration. Rather than interpret any behaviours as absolute positive/desirable interaction, we analysed differences in behaviour to reflect on what patterns across distinct control situations indicate. As hinted above, consistent patterns of altered engagement upon changes in control conditions might suggest that lemurs responded to the availability of control in its own right, independently of proximity's links to affect, curiosity, or other motivations. To address another crucial aspect of the phenomena at issue, we use 'collaboration' to denote zoo visitors and lemurs controlling the system together.

Irrespective of the above definitions, applying these terms, 'engagement', and other HCI concepts to animals requires further caveats. Some scholars even argue that such notions utterly fail to suit animal use of computer systems [47]. After all, we do not know how much an animal can meaningfully interact at what levels, and what animals comprehend or intend when interacting has gone largely unexplored [45, 99]. Hence, while reporting on numerical measurements of lemurs' interactions, we must be mindful that these say nothing directly about any animal's goals or perceptions [45]. Just as the issue of ambiguous interpretation plagues the field of child–computer interaction and work with some adults where direct communication is unavailable, the intention behind the interaction loop may be immensely difficult to discern [111]. Critically, interactions between animals and technological devices may be deliberate, accidental, or some combination of the two. Mere proximity provides no way of distinguishing. While our study applied mitigation strategies in connection with a known interaction method, we remain keenly aware of ample room for misunderstandings, particularly when interpreting lemur behaviour.

While our chosen terminology serves the practical aim of examining where animals and technology meet, we use it not in an HCI-bound fashion but in a far broader sense, to describe observable animal behaviours. Especially in collaboration scenarios, the window to what constitutes meaningful engagement is clouded. Though we cannot definitively confirm mutual understanding or

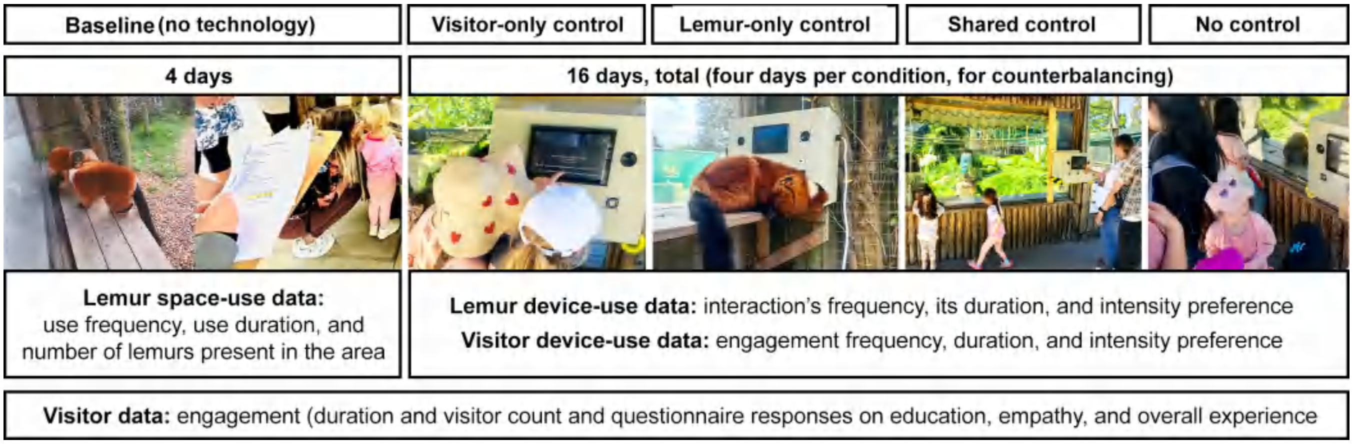


Figure 6: A diagram summarising the study method.

intention, carefully investigating how collaboration affects what lemurs do can bring us closer to knowledge of their perspective on the system and, in turn, honing our interpretation of these concepts.

4.2 Participants

The animals taking part in the study were five red-ruffed lemurs housed at the safari park. They live as a cohesive group: P1 (female, 22 years) is the mother of P2 (female, 8 years), P3 (female, 5 years), and P4 (female, 4 years), and P2 is the mother of P5 (male, 3 years). We selected red-ruffed lemurs for their status as critically endangered; their long-term conservation requires enrichment interventions in captivity [10, 67].

In all, 696 valid questionnaire forms were collected from zoo visitors, comprising 14.94% children under 15 (n=104), 69.40% individuals aged 15–60 (n=483), and 15.66% adults above age 60 (n=109). Their mean age was 37.07 years. The gender distribution was 44.78% male (n=312), 53.93% female (n=375), 0.86% non-binary/other (n=6), and 0.43% undisclosed (n=3). Frequency of visits to the host zoo varied, with 7.61% of respondents being first-time visitors and 10.49% reporting less-than-annual visits. As for regular visits, 30.75% reported coming annually, 29.74% twice a year, 15.95% quarterly, and 5.46% more often. With regard to the red-ruffed-lemur enclosure specifically, 68.30% were first-time visitors, 20.84% had visited previously, and 10.86% reported paying regular visits to the enclosure. The other three humans taking part, the above-mentioned zookeepers who offered professional insight into the behaviour, welfare, and technology interaction of the lemurs under their care, all were female. Keeper 1 had four months of experience, Keeper 2 (the team supervisor) had 19 years', and Keeper 3 had nine years' experience.

4.3 Ethics and Welfare Monitoring

Ethics approval was granted by the Blair Drummond Safari Park Board, the Veterinary Ethics Committee of the University of Glasgow (under ID EA1523), and the university's Computer Science Ethics Committee (approval 300230165). In addition to obtaining formal approval, we followed a welfare-centred protocol comprising continuous monitoring, autonomy, precautionary scheduling, and the principle of minimal disruption. *CreatureConnect* operated only during the daytime, never overnight, so zookeepers could continuously monitor welfare in line with the facility's established behaviour-assessment procedures. Whenever keepers judged continued exposure inadvisable, device operation was immediately paused. In practice, no such pauses were required during the study period, as no adverse welfare indicators were observed. For genuine autonomy, we systematically ensured voluntary access and disengagement, with no training or food attraction involved. Although operationalising some visitor control was inherent to the design, we took care to keep stimulus intensities within limits validated as welfare-safe. So as not to upset the lemurs' normal daily routines and to avoid continuous exposure, the system operated for five hours per day, four days a week. Enclosure layout and husbandry routines remained unchanged to guarantee that the system functioned as optional enrichment rather than imposing an unavoidable intervention.

5 THE ANALYSIS APPROACH AND MATERIAL

At no point in the study did any system failures occur, and no zookeepers, researchers, or primatologists reported negative indicators that would have prompted early termination. Cross-checking the lemur-side logs with video data made sure all instances factored in were lemur-triggered (this excluded 11 zookeeper-initiated events). False negatives, in contrast, wherein a lemur entered the space without the system activating, accounted for 29 incidents (5% of all interactions); our analysis did not include these, since *CreatureConnect* did not output stimuli. Since we had used randomisation, we checked also that the stimuli were balanced across conditions, which they were (video+audio = 180, video+smell = 181, audio+smell = 180). All analysis used the R programming language.

For answers to RQ1, we carried out Kolmogorov–Smirnov tests for differences in technology interactions (by lemurs and humans) among the control settings. These showed significant differences for the number of lemurs, time in the space, and visits to it (all $p < .001$); lemurs' individual-level vs. group system use (for frequency and duration, all $p < .001$); and how long human visitors interacted with the system ($p < .001$). For non-normal variables, we used the Aligned Rank Transform (ART) with Wilcoxon rank-sum *post hoc* tests and Holm correction, since the analysis compared group-level interaction and engagement events rather than equivalent individual-level paired observations. To probe patterns in lemur–system interaction (frequency and duration) over time, we used linear regression. As no prior work supplied effect-size estimates for cross-species shared-control systems and since the red-ruffed-lemur sample size was fixed, we report observed effect sizes (r). To assess which stimulus intensities the humans and lemurs preferred choosing, we employed chi-squared goodness-of-fit testing with Holm correction.

To explore effects on visitors per RQ2, we examined all 696 completed questionnaires (after filtering out partly filled-in forms from the set of 705 collected from visitors to the enclosure). Here too, we used Kolmogorov–Smirnov tests, which identified three normally distributed variables: education (TCOR-gauged) (p = .46), empathy (p = .17), and overall experience of *CreatureConnect* (p = .07). We analysed these via one-way ANOVA with Tukey's HSD *post hoc* tests. The remaining, non-normal variables underwent ART analysis with Wilcoxon rank-sum *post hoc* testing and Holm correction.

6 RESULTS

The total duration of lemur interaction with *CreatureConnect*, over all four technology conditions, was 23,656 seconds. On average, lemurs used the system for 24.64 minutes in total per day, with a mean of 33.81 interactions a day. Average interaction time over the 541 occasions was 43.73 seconds. On average, we observed 807 human visitors daily (breakdown of the 16,139 visits: 2,418 in the baseline condition; 3,379 in the visitor-control-only one, 3,054 in the lemur-control one, 4,112 in the shared-control setting, and 3,176 in no-control technology use) and collected 35 questionnaires per day (corresponding distribution of valid forms: 119, 152, 125, 154, and 146). We recorded 1,719 *CreatureConnect* interaction events across the four technology conditions: 466 times in the visitor-only setting, 525 with shared control, and 364 each in the lemur- and no-control condition, averaging 107.43 interactions/day. The discussion below proceeds from our analysis of these observations and other data, considering RQ1 and RQ2 in turn.

6.1 How *CreatureConnect* Control Conditions Affected Lemur Interactions (RQ1)

Neither the number of lemurs entering the technology space nor their visits/day count differed significantly between conditions (lemur count: $F(4, 594) = 1.16$, $p = .44$; visit count: $F(4, 15) = .64$, $p = .64$); see Table 1. However, the amount of time spent in lemurs' *CreatureConnect* space showed significant variation ($F(4, 594) = 4.18$, $p = .003$). Lemurs used the relevant space for significantly longer spans when the technology was available see Table 2), thus demonstrating greater interaction when it was active. Reflecting on the system's impact, Keeper 2 remarked that 'the lemurs spent a lot of time around it — they quite liked the technology', and Keeper 1 described them 'sitting on the box… hanging around it' and 'lying over by it, kind of sleeping around it'.

Interesting, interactions in the technology space were shortest with lemur-only control, significantly briefer than in the shared-, visitor-only-, and no-control condition. Having detected this pattern, Keeper 2 mused that perhaps the lemurs 'were more engaged when the public controlled the system alongside them'. Reflecting on these findings, Keeper 3 suggested that 'maybe the lemurs just didn't want to control it entirely by themselves'.

As for tendencies in lemurs' chosen stimulus intensity, Table 3 shows interaction patterns wherein the animals typically choose medium audio volume (53%; χ^2=17.31, adj. $p < .001$), high air flow for olfactory stimuli (67%; χ^2=53.49, adj. $p < .001$), and high brightness for videos (59%; χ^2=31.36, adj. $p < .001$). These differential preferences across modes suggest that lemurs understood and deliberately adjusted stimulus intensity, rather than selecting randomly. Keeper 3 expressed this sense thus: the lemurs 'seemed to understand that being close triggered something stronger, and they often approached to elicit scent'.

Although both duration and frequency of system use display downward trends over time (see Figure 7 and 8, respectively), neither decline reached statistical significance. This implies the absence of a substantial novelty effect – that is, of a change in response prompted by repeated stimulation (frequency: r = -.43, p = .10, R^2 = .19; duration: r = -.45, p = .08, R^2 = .20). However, when examined by control condition, lemur engagement duration and frequency exhibited different temporal patterns over time. Under visitor-only control, both interaction frequency (r = -.58, p = .42, R^2 = .34) and duration (r = -.52, p = .48, R^2 = .27) showed moderate but non-significant negative trends over time. Under lemur-only control, neither frequency nor duration varied with study day (frequency: r = -.02, p = .98, $R^2 < .001$; duration: r = .004, p = .99, $R^2 < .001$). The shared-control condition exhibited strong but non-significant trends, with frequency decreasing (r = -.79, p = .21, R^2 = .63) and duration increasing (r = .76, p = .24, R^2 = .58). By contrast, in the no-control condition, interaction duration declined significantly over time (r = -.99, p = .01, R^2 = .97), while frequency did not (r = -.54, p = .46, R^2 = .29). Also, lemur–system interactions did not vary significantly by one-hour window (duration: $\chi^2(4) = 5.65, p = .23, W = .09$; frequency: $\chi^2(4) = 4.12, p = .39, W = .06$). This points to consistent engagement with the device irrespective of the time of day. Reflecting on these results, Keeper 2 remarked that the system is 'definitely useful for lemurs, even over long periods', a musing that contrasts with the typical longevity issues of computer-based enrichment systems.

Half of the time, the lemurs used *CreatureConnect* as individuals (50.08% of occasions), while the rest of the time was split among groups of two (33.26%), three (14.98%), and four (1.68%). The duration of an engagement event did not differ between single lemurs' interactions and group ones ($F(3, 346) = .97$, $p = .41$). These results demonstrate that the system can function as a part of social interaction and for individuals' enrichment. When asked about group and single-animal interactions with the system, Keeper 2 noted that 'the younger females showed the strongest interest', which points to individual-level differences.

Investigating other impact factors, we looked for correlations of lemur–device interaction duration or frequency with the visitor–system equivalents. No significant relationship was visible (duration: r = -.27, p = .66; frequency: r = -.15, p = .57), so lemur engagement probably did not co-vary with visitor activity.

	Baseline	Visitor-only	Lemur-only	Shared	No-control
Baseline	–	z=-1.10, p=.47	z=-1.105, p=.25	z=-1.46, p=.67	z=-.73, p=.77
Visitor-only	r=-.55	–	z=-.37, p=.56	z=1.10, p=.89	z=-.55, p=.88
Lemur-only	r=-.55	r=-.18	–	z=-.73, p=1	z=.37, p=.38
Shared	r=-.73	r=.55	r=-.37	–	z=1.10, p=.56
No-control	r=-.37	r=-.27	r=.18	r=.55	–

Table 1: How frequently lemurs visited the system space across all study conditions. Unadjusted p-values and corresponding r and z statistics are reported, as Holm-adjusted values were uniformly equal to 1 and thus uninformative.

	Baseline	Visitor-only	Lemur-only	Shared	No-control
Baseline	–	z=-2.88, p=.004*	z=-1.96, p=.047*	z=-2.88, p=.004*	z=-3.29, p<.001*
Visitor-only	r=.24	–	z=4.42, p<.001*	z=-1.04, p=.30	z=-1.88, p=.06
Lemur-only	r=.18	r=.29	–	z=-5.86, p<.001*	z=-3.85, p<.001*
Shared	r=.25	r=.09	r=.37	–	z=-1.02, p=.31
No-control	r=.30	r=.17	r=.24	r=.09	–

Table 2: The time lemurs spent in the technology-equipped space, compared across all study conditions, with p-values and also r and z values (* indicates significance).

Sense mode	Low-level	Medium	Intense	χ^2	Adj. p
Auditory	24%	**53%**	23%	17.31	$< .001^*$
Olfactory	10%	23%	**67%**	53.49	$< .001^*$
Visual	17%	24%	**59%**	31.36	$< .001^*$

Table 3: Lemurs' triggering of stimuli of each intensity, by percentage of occasions (* indicates statistically significant preferences.

6.2 How Control via *CreatureConnect* Influences Visitor Interactions (RQ1)

Turning our attention to the humans, we found that differences in control significantly affected the length of visitor interactions with *CreatureConnect* ($F(3, 1715) = 36.99$, $p < .001$; see Table 4). Visitors used the system significantly longer in the shared-control condition than when either the lemurs had full control ($r = .26$, adj. $p < .001$) or neither party had any control ($r = .34$, adj. $p < .001$). The shared-control condition featured frequently in comments by visitors, such as P432, who found it 'amazing to hear their calls in response to the smell I triggered. They also changed the video brightness for me'. Likewise, P183 stated that 'it was a magical experience sharing this moment with them'. Having identified this pattern, Keeper 3 said that 'visitors stayed longer because they were interacting with the box, and they were especially drawn [in] when they saw the lemurs using it'. Even granting visitors complete control yielded greater engagement, by our metrics. When controlling the system on their own, they still continued with it significantly longer than when only lemurs controlled the system ($r = .15$, adj. $p < .001$) or when neither party did ($r = .20$, $p < .001$). Remarking on the visitor-control-only condition, P220 summed up: 'I loved seeing the lemurs respond to the scent I chose.'

As the lemurs did, visitors exhibited intensity preferences, significantly favouring high-intensity stimuli across all sensory modes (see Table 5). Keeper 3 suggested that this preference stemmed from 'people probably just think[ing] stronger intensity will get more lemurs' reacting. Visitor comments support this conclusion; for instance, P123 said that 'they moved closer to the screen when I increased the brightness to the highest level' and P199 said the lemurs 'seemed to enjoy the strong mango smell I controlled'.

6.3 *CreatureConnect*'s Impact on Visitor Engagement, Education, Empathy, and Experience (RQ2)

Visitor engagement: Visitor engagement, represented by the number of humans visiting the enclosure area ($F(4, 7311) = 617.15$, $p < .001$) and how long each stayed near the enclosure ($F(4, 7311) = 1583.90$, $p < .001$), varied significantly across all conditions. Tables 6 and 7 present the figures for these. When the technology was available, more visitors were attracted than in the baseline condition, and they spent longer at the enclosure (all $r > .16$, all adj. $p < .001$). When sharing control of *CreatureConnect* with lemurs, visitors spent longer by the enclosure than in any other technology-use condition (visitor-only control $r = .36$ and adj. $p < .001$, lemur-only control $r = .46$ and adj. $p < .001$, and no control $r = .43$ and adj. $p < .001$), and we noticed more people visiting the enclosure area (all $r > .06$, all adj. $p < .001$). Visitor-only control proved next most popular, followed by the no-control condition and lemur-only control, with the baseline condition attracting the fewest visitors. Visitors spoke of their attraction to the exhibit with its technology in terms such as these: 'The idea of adjusting the sensory intensity to attract lemurs is interesting. I tried to attract lemurs, and they actually came to use it' (P449). Visitors commented on lack of control too, recommending that in future it would be good to work together when

	Visitor-only	Lemur-only	Shared	No-control
Visitor-only	–	z=4.32, p<.001*	z=-1.89, p=.06	z=5.76, p<.001*
Lemur-only	r=.15	–	z=-7.75, p<.001*	z=1.89, p=.12
Shared	r=.06	r=.26	–	z=10.14, p<.001*
No-control	r=.20	r=.07	r=.34	–

Table 4: Pairwise comparison of how long visitors interacted with the *CreatureConnect* system across the four deployment conditions, where * indicates statistical significance.

Sense mode	Low-level	Medium	Intense	χ^2	Adj. *p*
Auditory	20%	21%	**59%**	29.36	$< .001^*$
Olfactory	16%	29%	**55%**	23.98	$< .001^*$
Visual	20%	28%	**52%**	17.16	$< .001^*$

Table 5: Visitor activations of stimuli of each intensity level, as percentages (* indicates a significant preference).

humans are not given control: 'Lemurs can control the intensity, but I can't. It would be great if I could control that as well' (P296), 'the experience of only the lemur being able to control it is not the best' (P315), etc. Finally, Keeper 3 remarked on the curiosity effect, 'even just with the box sitting inside, visitors were interested in seeing what it was. It attracts more people towards the enclosure, doing something different'.

Visitor education: We found that all conditions featuring the technology drew visitors' conversation more toward education-linked topics, to a statistically significant extent ($F(4, 691) = 158.41$, $p < .001$). As Table 8 demonstrates, the shared-control condition exerted the strongest human-education effect. Free-form feedback echoed this finding: Keeper 3 noted that the shared-control condition 'gave visitors something different to go home with', underscoring its role in fostering learning and reflection. Visitors too highlighted the educational impact. For instance, P431 remarked that 'I learned what lemurs eat', and P406 said 'I released the apple scent; lemurs like fruit'.

Empathy in visitors: Likewise, visitor empathy differed significantly over the five conditions ($F(4, 691) = 98.65$, $p < .001$) (Table 9). As with education, the baseline condition produced significantly lower figures than all other conditions (all adj. $p < .001$). Visitor empathy for lemurs was discussed most by those exposed to the shared-control condition (95%), though we found no significant differences in this regard between the shared- and no-control condition (95% and 85%, respectively, for diff. = .10; adj. $p = .82$). The shared-control condition did produce empathy for lemurs significantly more often than visitor-only control (diff. = .17, with adj. $p = .03$) and than lemur-only control (diff. = .26; adj. $p < .001$). Even the no-control setting yielded higher empathy scores than the visitor-only-control one (diff. = .07, with adj. $p = .17$); however, this difference did not reach statistical significance. Visitors regarded understanding lemurs in relation to themselves as a part of forming empathy, as P450 stressed: 'It is interesting to compare lemur and visitor choices on the same interface.' A more profound effect was evident for P585, who said 'I saw them reacting to a gentle rhythm, and I felt the same great integration of senses as lemurs'. Our findings in this regard meshed with comments by Keeper 3, who noted that 'instead of having to watch [the] lemurs, visitors felt they had done something for the lemurs today when they can use the boxes with lemurs, together'. Joint use fostered a stronger sense of emotional connection to lemurs. Empathy has close ties also to anthropomorphism, wherein people ascribe human qualities to animals so as to understand and relate to them. Keeper 3 identified the latter too, observing that visitors even joked with zoo personnel that the lemurs were 'spoiled, like having a TV as people'.

Visitors' overall experience: Analysis of visitors' overall experience at the enclosure revealed that all four technology-present conditions significantly outperformed the no-technology one in human experience ratings ($r = .35$, adj. $p < .001$). Shared control received the highest score from visitors (M=4.53), significantly surpassing visitor-only control (M=4.09), no control (M=3.92), and lemur-only control (M=3.87, all adj. $p < .001$).

Asking about plans to visit the enclosure again elicited expression of significantly greater revisit intentions among visitors exposed to the shared-control condition relative to the baseline ($F(4, 691) = 158.31$, $p < .001$): 87% of them expressed a strong desire to return, compared to only 3% of those with a no-technology experience. Shared control also outperformed visitor-only control and no control in this regard (both 77%, with adj. $p < .05$) but not lemur-only control (80%).

The opinions of visitors rating *CreatureConnect* depended significantly on the technology-control scenario ($F(3, 573) = 1361.17$, $p < .001$). Ratings from exposure to the system's shared-control condition were the highest (M=4.83), significantly exceeding those from the visitor-only-control (M=4.08), no-control (M=3.84), and lemur-only-control condition (M=3.75) (all with adj. $p < .001$). Keeper 1 summed up: 'Visitors prefer doing something, like using this technology, rather than just listening to [the keeper] talk.' In conjunction with their ratings, visitors described the technology as of '[n]ice design and engages the kids a lot!' (P663) and said that they 'loved how interactive the technology was. It really held both the lemurs' and our attention' (P684). Some visitors, however, left negative comments, which focused on the animals' emotions – 'it's a bit of a shame to see them like that' (P48), 'none look happy' (P64), and

	Baseline	Visitor-only	Lemur-only	Shared	No-control
Baseline	–	z=-31.63, p<.001*	z=-28.94, p<.001*	z=-34.57, p<.001*	z=-20.72, p<.001*
Visitor-only	r=.61	–	z=7.80, p<.001*	z=-3.38, p<.001*	z=20.44, p<.001*
Lemur-only	r=.55	r=.14	–	z=-11.40, p<.001*	z=14.18, p<.001*
Shared	r=.65	r=.06	r=.20	–	z=23.69, p<.001*
No-control	r=.41	r=.38	r=.26	r=.43	–

Table 6: Pairwise comparison of visitor counts for the red-ruffed lemurs' enclosure across the five types of control (* denotes significance).

	Baseline	Visitor-only	Lemur-only	Shared	No-control
Baseline	–	z=-24.37, p<.001*	z=-23.68, p<.001*	z=-8.51, p<.001*	z=-22.24, p<.001*
Visitor-only	r=.47	–	z=12.26, p<.001*	z=-20.26, p<.001*	z=12.91, p<.001*
Lemur-only	r=.45	r=.22	–	z=-26.22, p<.001*	z=7.63, p<.001*
Shared	r=.16	r=.36	r=.46	– z=24.24, p<.001*	
No-control	r=.44	r=.24	r=.14	r=.44	–

Table 7: Pairwise comparison of per-visit duration (i.e., single-visit duration) for all visits to the lemurs' enclosure across the five control types (* denotes statistical significance).

	Baseline	Visitor-only	Lemur-only	Shared	No-control
Management	10%	87%	82%	89%	87%
Social factors	22%	80%	76%	96%	82%
The exhibit	27%	74%	74%	94%	81%
Location	28%	80%	77%	95%	82%
Information	35%	84%	74%	89%	88%
Emotions	48%	82%	71%	91%	79%
Body parts	39%	86%	79%	93%	85%
Behaviours	20%	79%	74%	92%	85%
Names	33%	77%	75%	94%	83%
Mean	29%	**81%**	**76%**	**93%**	**84%**

Table 8: The percentage of visitors who reported discussing particular topics while at the lemur enclosure, for each control setting.

	Baseline	Visitor-only	Lemur-only	Shared	No-control
Concern	25%	80%	74%	95%	81%
Consideration	14%	74%	65%	95%	90%
Connection	22%	79%	68%	94%	85%
Mean	20%	**78%**	**69%**	**95%**	**85%**

Table 9: The percentage of visitors in each control setting who reported emotional empathy with the red-ruffed lemurs.

that interaction on lemurs' part was lacking: 'not much happened; they were sleeping' (P78). Concerns about negative impacts were expressed too. For instance, 'when they hear the music, they run away' (P290), and a few visitors worried that the technology might have negative effects on the lemurs since it could 'antagonise them' (P81) and since the interactivity did not seem clear for lemur or human use in that it was 'hard to control the machine' (P296).

Effects of Visitors' System Use and of Observing Others': While 88% of visitors used *CreatureConnect* themselves, some only observed other humans doing so. As P380 mentioned, it can be 'fun to see other people using it with the lemurs'. Visitors frequently echoed the sentiment cited above that *CreatureConnect* 'engages the kids a lot!'. The visitor using vs. observing others did not significantly influence the statistics for engagement (M = 4.19 vs. 4.12; r = .05, adj. p = .39), education (M = 4.16 vs. 4.07; r = .07, adj. p = .21), empathy (M = 4.17 vs. 4.12; r = .02, adj. p = .61), or overall experience (M = 4.16 vs. 4.04; r = .06, adj. p = .16). Participant 215's comment that '[w]atching others use the box was already enjoyable; I didn't need to try it myself to feel involved' indicates that observing other visitors' interactions created a positive experience on its own. In contrast, whether the visitor observed lemurs use the system had a marked effect: the 76% of people who reported seeing a lemur interact with the device showed significantly higher average scores for engagement (M = 4.19 vs. 3.96; r = .26, adj. p < .001), education (M = 4.21 vs. 3.97; r = .25, adj. p < .001), empathy (M = 4.20 vs.

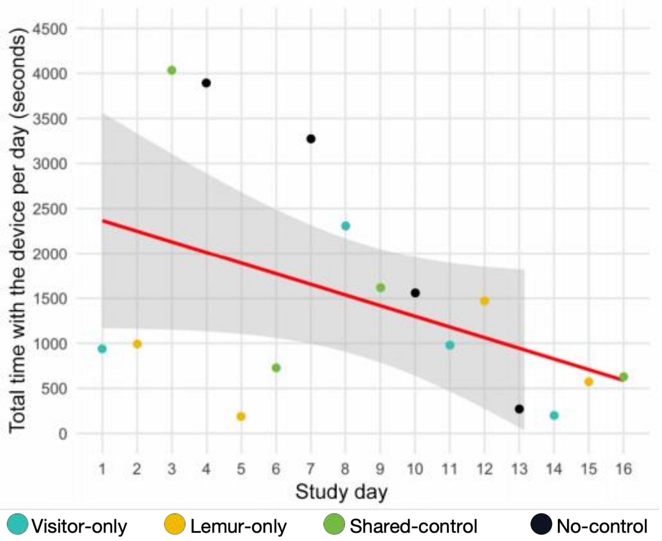


Figure 7: Lemur–device interaction time (in seconds) for each day, with a linear trend line. Points are plotted for specific control-type conditions across the 16 technology-use days, coloured by condition.

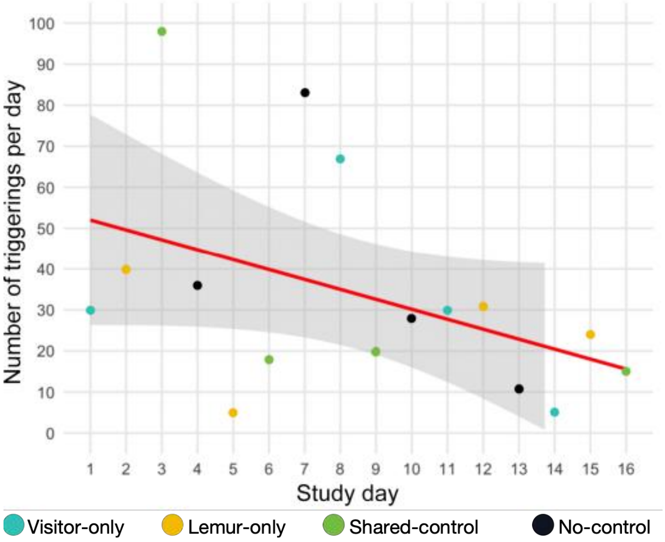


Figure 8: Each day's frequency of lemur-triggered device activation, with a linear trend line. Data points, with colours denoting the relevant type of control, are plotted to correspond to specific conditions across the study's span.

4.03; r = .11, adj. p = .01), and the overall experience (M = 4.20 vs. 3.96; r = .20, adj. p < .001). Illustrative comments are P414's remark 'Since the lemurs didn't move but stayed near the device, people gathered around to watch. Very engaging!' and P352's note that 'I didn't see them use it today, so the experience felt less special'. Hence, we conclude that not using the system oneself but observing lemur–system interaction was the key factor in visitors' engagement, education, empathy, and general experience. The former had no significant influence on the figures for these, while the latter led to higher scores across the board.

Visitors made several recommendations for future research and improvements related to *CreatureConnect*. Some proposed exploring lemurs' responses to other stimuli; e.g., humans could 'vote on the next stimuli' (P665) or 'choose which songs to play for the lemurs' (P281), while others mentioned testing alternative interaction mechanisms for lemurs, such as letting them 'tap the screen like we do' (P491). Some visitors requested clearer visuals or audio cues for the interface, to enhance its education value. For example, P698 suggested adding 'a lemur profile for each individual' while several other participants asked for graphical explanations of lemurs' general responses to certain stimuli (P485, P537, P549, and P635). Also, to improve accessibility, especially for children, P676 recommended 'audio narration for younger kids who can't read'. Finally, similar systems could be implemented elsewhere at the zoo: 'I hope you can try it with other species too' (P585). These ideas highlight several possible paths to enhancing animal well-being while also helping visitors via clearer cues that support better understanding of lemur behaviour.

6.4 Computers for Shared Control vs. Viewing of Information

For a broader picture of the connections stimulated, let us 'zoom out' from *CreatureConnect*, which lets lemurs and humans jointly control a bimodal system, via comparison with our previous system coined *SensorySafari* [127] which allowed zoo visitors to view information about lemurs' interaction with a multimodal system. The two studies were done in the same zoo setting, with the same lemur group, so data from our teams previous seperated devices [127] can be plotted directly against figures for our connected devices. We compared the condition wherein *SensorySafari* was available for both lemurs and zoo visitors to when lemurs and humans controlled *CreatureConnect* together. Since the studies were performed at different times of the year, with visitor counts diverging accordingly, we examined human engagement by comparing duration and frequency to the respective study's baseline. Table 10 presents a summary.

Comparing conversation topics under each of the nine distinct education categories, we found significant differences for three: 1) *SensorySafari*, the separated system, elicited more management-related discussion (W=19,550, p = .003, Z=1.26, r = .06) while *CreatureConnect*, our connected system, elicited more socially focused (W=26,108, p < .001, Z=4.08, r = .20) and name-related conversation (W=25,898, p < .001, Z=3.91, r = .19). 2). For empathy, all three figures were higher with *CreatureConnect*: concern (W=24,876, p < .001, Z=3.08, r = .15), consideration (W=23,045, p = .006, Z=1.59, r = .08), and connection with the lemurs (W=22,550, p = .021, Z=1.18, r = .06). Finally, 3) visitor experience of the enclosure showed significant differences but only with regard to the technology-use experience, with higher ratings for *CreatureConnect* (W=17,785; p = .001; Z=2.70; r = .13).

Within comparable one-hour windows (11am to 4pm in both studies), lemurs spent significantly more time interacting with *CreatureConnect* than with *SensorySafari* (p < .001, r = .059). Their interaction frequency, on the other hand, did not differ significantly between the two systems (p > .51, r = .047).

Dimension	**SensorySafari** (separate devices)	**CreatureConnect** (connected devices)
Visitor engagement	Average time in the enclosure area: 546.96 s per visitor (3.86 times the baseline average)	Average time in the enclosure area: 534.51 s per visitor (2.32 times the baseline average)
Visitor conversation topics	Management: discussed by 96% (+) Social factors: discussed by 69% (-) Naming: discussed by 70% (-)	Management: discussed by 89% (-) Social factors: discussed by 96% (+) Naming: discussed by 94% (+)
Empathy among visitors	Concern: reported by 76% (-) Thoughts/feelings: reported by 84% (-) Connection: reported by 88% (-)	Concern: reported by 84% (+) Thoughts/feelings: reported by 95% (+) Connection: reported by 94% (+)
Visitor ratings of the technology experience	4.56 out of 5 (-)	4.83 out of 5 (+)
Other visitor-related outcomes	Visibility of the device improves education. Seeing other visitors' interactions improves results by all metrics.	Seeing interaction by visitors or lemurs improves results by all metrics. Visitors set all stimuli to high intensity.
Lemur engagement	Engagement was stronger with multimodal than unimodal stimuli. Visual-only stimuli brought the least engagement. Interaction episodes lasted shorter than with *CreatureConnect*. (-)	Lemurs chose high visual and olfactory intensity and medium audio volume. Lemur-only control produced the least engagement. Event-specific durations were longer than with *SensorySafari*. (+)

Table 10: *SensorySafari* and *CreatureConnect* compared (with '+' denoting a statistically significantly better outcome for a given item and '–' used for the other system.

7 DISCUSSION

Our study delved into the effects of varying the control dynamics of a shared bimodal computer systems on lemurs and visitors in several respects. The most crucial findings are that lemurs interacted with our system least when they alone controlled it while humans interacted most when sharing control with the lemurs (RQ1) and that figures for visitor engagement, education, empathy, and overall experience were significantly better among the humans who had used the computer device alongside lemurs (RQ2). The findings, captured in Figure 9, are especially relevant in two domains of theory: what 'interaction' is in the context of AVIs and how control and choice affect humans and animals in an AVI.

7.1 Understanding Interaction in Animal–Visitor Settings

While we identified an impact of *CreatureConnect* on visitor and lemur behaviours, with lemurs engaging in fewer interactions with the system amid conditions of autonomous control, thereby answering RQ1, the underlying mechanisms remain unclear. Also, while lemurs' active use of the system demonstrates potential, impacts on animal welfare warrant further investigation. Although lemurs did not actively avoid the space (as their high interaction counts attest), this does not necessarily imply a positive effect on their well-being. While we cannot straightforwardly ask lemurs about their experience or the factors driving these behaviour patterns, the engagement persisting over 16 days does tell us something about the system's value, even if the type/nature of that value remains open to debate. One could suggest that the system offered an opportunity to engage directly with humans, a form of environmental enrichment in its own right [22]. This sparks deeper questions about how lemurs and humans understand their interactions with each other.

Cultivation of understanding between species is shaped in part by people's empathy, their education, and engagement with another species. Our answer to RQ2 is that *CreatureConnect* can enhance visitors' engagement, education, empathy, and overall experience of the system, especially in shared-control scenarios and compared to our previous separated systems [127]. We suspect this to be due to the system's guidance toward mutual understanding. Broader reflection on how humans and animals can develop shared understanding in the context of AVIs points to possible mediation by social cues. In human-to-human technology-mediated interaction, social cues often arise from observing others' actions or sensing co-presence, from inputs such as gaze, head motions, and hand gestures [39]. These cues are crucial for facilitating interaction between human users, especially in the absence of verbal communication [105]. Similarly, social cues present in animal–human interactions, such as gaze, body movements, and pointing, have been pinpointed as signals that at least some animals can recognise and respond to [97, 105]. Although scholars have not fully clarified which social cues lemurs in particular can recognise, evidence from various human–animal interactions suggests that social cues may mediate how members of one species understand and react to members of another in the context of zoo AVIs. While our findings suggest that visitor presence influenced lemur engagement, whether the

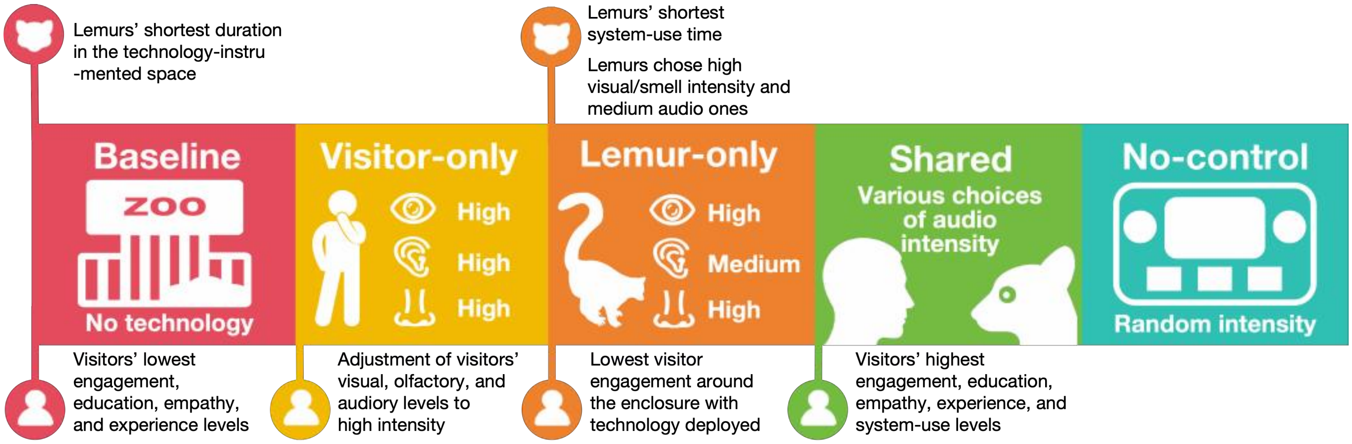


Figure 9: Key findings for all five distinct control-assignment conditions.

heightened interaction reflects sensitivity of this species to visitor-originated social cues remains unclear.

This leads us to the technology-design question of how social cues can be effectively established in AVIs. In our system, visitors had direct visual feedback from slider positions and from lemurs using their interface with *CreatureConnect*, while lemurs could observe visitor engagement in the space around the visitor device, the stimulus changes that followed, and the slider positions on their own screen. Of course, the lemurs might not have grasped the causal link between human actions and the system-initiated responses. That is, they may have lacked what animal-cognition scholars term the means–end connection: the recognition that one's action produces a specific outcome [85]. Accordingly, all mentions of interaction or shared control in this paper refer to observable reciprocal influence between species. We do not claim any evidence of lemurs' means–end understanding. Scholars must attend to the elephant in the room, then: how to enhance social cues in accordance with animal perspectives. Providing one seed for future work, studies with non-human primates have shown that some species take the gaze direction of others, including human experimenters, as guidance for their behaviour. The implication that gaze can act as a social cue in certain cross-species contexts [59] could inspire a design that, rather than display a slider position on two devices, establishes social cues by visually representing lemurs' and humans' actions of triggering the stimuli. For example, when visitors adjust intensity, the *CreatureConnect* screens could show a video of the corresponding human gaze direction and of the lemur's corresponding use of the system on the respective devices. This would extend the work in which Martin and colleagues found that chimpanzees can make strategic choices through seeing the joint-action cues from human users on their screen when playing a competitive game together [77]. Although we do not yet know whether lemurs can interpret facial cues of that kind and whether these animals fully understand links involving such cues, concrete visualisation signals of such a sort on their device screens might well enhance social cuing, particularly in situations wherein the lemurs are not facing the visitors or cannot localise sounds in their environment.

Alongside social cues, the shared interaction points to another critical aspect of whether lemurs and human visitors understand each other's actions with such systems – the intentions and responses of the other species in the system setting. Again, we cannot ascertain whether mutual understanding exists, as humans are locked out of lemurs' perceptions. While Haraway's 'becoming-with' concept [43] helps shed light on how entities grow attuned to each other through knowing, creating new forms of knowledge and hybrid identities, can such interconnectedness emerge from the brief, transitory interactions between zoo animals and visitors? In many respects, *CreatureConnect* creates hybrid 'contact zones' that are part machine, raising compelling questions about how machine-enabled spaces might facilitate shared understanding and nurture new forms of symbiotic being between the human and other species.

Stepping back, we posit that mutual understanding, or a deep sense of knowing, may not be essential for reaping education value for visitors and enrichment for lemurs via technologically mediated AVIs at zoos. Despite being informed of the system-interaction mechanics, visitors often could not tell whether lemurs were actively engaging vs. merely present around the device, especially in cases with multiple individuals nearby, yet they still began reflecting on the meaning and interpretation of lemurs interacting with computers (even when the lemurs were sleeping, in the cases of P78 and P352). Whatever technological shortcomings were present and irrespective of their philosophical musings, human visitors reported significantly stronger engagement, education, empathy, and overall-experience effects when lemurs were controlling or interacting with the device in tandem with them. Reflecting on our prior work, we also know that these reports are more significant in connected than separated systems [127] highlighting the benefit of the connected systems for humans. By the same token, while the study's lemurs may have been unaware of many facets of the control mechanisms, visitor involvement, and what linked visitor actions and the stimuli, all technology-present conditions brought significantly increased lemur engagement in the area around the device, especially when visitors were involved.

One crucial implication of our research is that ambiguity and possible impediments to mutual understanding do not necessarily cancel out the positive outcomes among human visitors. In combination, this result and the outcome of the lemurs always staying in the space longer when it was interactive than under baseline conditions suggest that mutual comprehension indeed might not be central for beneficial technology-based zoo AVIs. Hence, our findings call for ethics-focused reflection on cross-species interaction design for zoos, with specific attention to whether full mutual understanding is necessary for meaningful benefits and to well-grounded definition of genuine, value-creating animal–human interaction.

If authenticity of interaction matters, future work should more extensively probe ways to enable bidirectional engagement through technology design. On the other hand, irrelevance of whether the lemur or the human is genuinely interacting with the other species prompts a different question: does it matter if the animal and human participants are real? One could speculate about robotic devices preprogrammed to supply visitors and/or animals with perceived but illusory visitor–animal interaction. Such systems with artificial material could address practical limitations faced at zoos: sometimes animals are not on view, while on the other side visitor numbers might be low or the zoo may be closed. In fact, scholars have already proposed that robot animals with realistic behaviours might evoke visitor responses comparably to real animals [37]. While presenting robotic agents could create misleading illusions, sow seeds of doubt, etc., and thereby both reduce the education and emotional benefits for visitors and limit potential welfare benefits for real animals by paring back the opportunities to benefit from direct engagement with zoo visitors or the technology, it may be tempting. Amid ethics-related pressure and the practical challenges of involving live animals in research, housing animals at zoos, and maintaining the technology, simulated AVIs could grow increasingly central as technologies advance. It might be possible to replicate animal behaviours convincingly and facilitate/evoke both human and animal engagement, yet this is a slippery slope to entirely new sets of challenges, far beyond the scope of our work. Once the systems employ robotic or artificial stand-ins, there is no longer a real AVI; these interactions require direct animal–visitor interaction through technology.

7.2 Effects of Control and Choice on AVIs

Reflecting on how control and choice shape AVIs, as addressed in RQ1, we found that one potential source of value from the system for lemurs lies in choice and control over their environment. We designed *CreatureConnect* so as to let them choose (whether to engage, disengage, and adjust intensity) rather than remain passive observers in their environment. Yet our lemur-control-only condition, in which the animals had full authority over the system, produced the shortest lemur interactions with the device. Keeper 3's above-mentioned musing that the lemurs were reluctant to operate the system alone offers one possible explanation: perhaps they saw the shared interaction, as opposed to the stimulus provided, as the beneficial aspect. This interpretation is further consistent with a comparison to the *SensorySafari* system, which afforded observation-only AVIs [127] . For lemurs, co-present interaction with shifting control between visitors and lemurs may help sustain lemurs' engagement compared to animal-only interaction through providing unpredictability, which in itself may sustain interest. Together, these findings suggest that cross-species control allocation in shaping animal–system interaction is more complex than the simple idea that giving animals more control will lead to more interaction. Notwithstanding evidence that other primate species will use technological systems for the predictability and environmental influence provided rather than for specific stimuli or content [15], the role of shared vs. solo agency has not been studied in depth. Several systems do exist whereby people can use computers concurrently with animals [77, 135], yet mechanisms for shared control still present a puzzle. Variation within and between species adds complexity in this domain. Furthermore, what constitutes truly beneficial control varies by species [1, 2, 48], with the multifaceted ways in which choice and agency benefit animals remaining especially tricky to measure [83] in multi-user contexts.

By examining the benefits of control and choice, our work responded to the recognised centrality of control and choice over one's own life to animals' welfare (e.g., the facility-accreditation standards of the Association of Zoos and Aquariums deem these vital). Its results challenge the widely held assumption that greater control for animals correlates with more/stronger interactions with technology and, thereby, with their improved well-being [48, 75]. We posit that such views may be overly simplistic: as our lemur-control-only data attest, individuals' agency alone does not always boost engagement with technology. Animals' engagement with computer devices may hinge also on how control is shared and dynamically negotiated as interaction progresses, with the negotiation process itself contributing to the benefits. In essence, their welfare might gain more from the changes in control dynamics, the sequence of transitions in these, etc. Understanding control thus – as processual and fluid – aligns with viewing animal agency as a dynamic, interactive process rather than some static state [24]. This perspective is consistent with research wherein offering HCI control options via computers alone does not advance agency [70, 107] and in which joint operation that yields no responsive feedback or co-presence confers purely illusory control [70]. It is the extent of one's perceived influence on events affecting one (i.e., the person or animal's locus of control) that proves decisive [15, 70]. Critically, animals must develop a meaningful sense of control and of exercising agency before they can attribute system responses to their own actions.

The nature/extent of the choice matters too. *CreatureConnect*'s design offers a restricted landscape of choice: an option of (de) activating the interface and of adjusting the intensity of its stimuli. Though this improves on the choice range of typical animal–computer systems (on/off), it remains quite limited. To address the other extreme, choice overload from facing numerous or rapidly changing options [84], HCI design presents structured choices. For instance, navigation menus may guide the user through branches of options, with headings that remain consistent between sections/applications [84, 117]. We do not yet know whether animals interacting with computers might benefit from structured choice presentation, such as approaches that introduce options gradually or arrange them in distinct categories, though some researchers have already extended these HCI-anchored choice structures to such devices for animals as speech-board menus for parrots that group elements hierarchically and by category [26]. The experience of choice in such work remains unclear, just as our system, nearer the middle of the continuum, may or may not have provided genuine choice beyond basic activation and conditions. Perhaps it merely exposed users to different control settings. After all, the lemurs had no say in the control arrangements as we varied who controlled the stimuli from one day to the next. Our design might have been able to grant them some choice in this regard, expanding their options. Along similar lines, although lemurs interacted most with the device under shared-, human-only-, and random-control conditions, we recommend that such systems leave even the least preferred control assignments (here, lemur-only control) available to choose from. As noted above, some animals favour larger sets of options even if this requires them to select suboptimal conditions. Lemurs might, similarly to chimpanzees [30], value increased choice regardless of their interaction patterns.

When implementing more choice and control for animals in captivity, zoos must factor in choice and control for human visitors too. In many ways, this reflects the more general balancing act between the two aims of zoo environments. It is insufficient to consider animal enrichment, visitor education, or animal agency in isolation; what matters is how control is distributed, as each configuration of technology-mediated shared control can constrain, moderate, or facilitate AVIs in particular ways. This highlights a key consideration behind the sharing of control: should allocation prioritise animals' agency (via their greater control) or strive for meaningfully balancing control between species? Our findings suggest that meaningful balance, rather than maximal animal or human control, may optimise outcomes for both.

7.3 Reflections on Methodology

Our daily change of control conditions, while preventing order effects, may have hindered lemurs' forming of solid associations between their actions and system responses. That is, it could have led to what Norman [88] has called a 'gulf of execution', a mismatch between user intentions and system feedback. This problem points to a crucial methodological challenge in research such as ours: how to connect the control with predictable control patterns that animals can understand. Animals sometimes make seemingly irrational choices when encountering inconsistent reward structures [138] or numerous options [116]. One could argue for implementing longer periods for each condition (greater stability should help the animals learn the system's patterns) or for crafting adaptive mechanisms that clearly signal control changes to the animal users. Tensions inherent to ACI rear their head here: researchers must navigate the need for experimental rigour and the cognitive needs of animal participants, all while managing the habitat effects that every technology introduces.

Further methodological reflection led us to recognise that the interaction modality itself, proximity, may have influenced the sense of control. Scholars of ACI have found that onscreen buttons' size, physical button mechanisms, and non-button interfaces all shape responses in some way; the reliability of input recognition suffers when the design does not cater to specific animal anatomies [40, 64, 101]. Even opting for a proximity-based interface may constrain the expression of agency, whatever the control-allocation structure.

Comparing our shared-control system with our previous system of isolated devices [127] revealed five key axes of divergence in method: system architecture, interaction mode and goal, stimulus selection, control distribution, and transparency of lemur behaviour (see Table 11). While both studies pursued the broader aim of enrichment for zoo animals coupled with support for visitor engagement, the move from a single-species system to a multi-species one demands methodological reorientation. Where our previous approach [127] treats animals and humans as parallel users whose behaviours can be independently measured and reasoned about, our system had to embed both species in the same interactional loop. This demanded methodological attention not only to the interface mechanisms but also to the relational dynamics that arise when two species share control of a single technological event.

Beyond procedural contrasts, the methods represent different epistemic commitments. These, in turn shape the validity, replicability, and interpretive space of each study. *SensorySafari* system offers high internal validity by structurally reducing cross-species confounding; this enables 'cleaner' attribution of stimulus effects and supports more conventional causal inference. *CreatureConnect*, in contrast, embraces the methodological openness inherent in co-present, co-active interaction. This opens a window to emergent patterns, forms of mutual influence, negotiation, and asymmetry that a separation-based architecture cannot access. Simultaneously, though, the means of revealing these dynamics limits the isolation of discrete effects: behaviours becoming co-constituted complicates efforts to ascribe changes to one species or the other. The locus of enquiry shifts from individual responses to the relational character of multi-species interaction. The methodological and theoretical scope of what the system can uncover expands, but so does the number of dimensions.

7.4 Implications for the HCI Field

The finding that lemurs and human visitors differed in their preferred audio intensities underscores that sensory feedback is not a neutral signal but a perceptual event shaped by species- and individual-specific sensitivities. We can point to parallel challenges evident in human-only contexts, where cultural background, physical conditions, and cognitive capacity, etc. inform divergent experiences of identical stimuli [52]. Such HCI techniques as customisable volume and notifications already acknowledge some aspects of perceptual diversity among human users; our findings extend this recognition to cross-species contexts. This advances ACI while also adding to HCI's awareness – the extreme case of species differences can sensitise design to diversity among human users.

Our findings can help sharpen HCI work focused on cooperative computing, which emphasises that technologies mediate relations both between people and of people with their environments, while also foregrounding participation and sharing as intertwined themes [9]. Also, taking the concept of collaboration beyond humans may inform reconsidering what collaboration means in HCI contexts. Specifically, our shared bimodal system functions as what Bødker has termed a common artefact [9], bringing human visitors and animals together and enabling cross-species interaction. In this process, technology serves not as a mere functional device but as a mediator of interspecies relations, supporting interaction and collaboration under conditions of unequal agency and understanding. As HCI continues to explore human–AI collaboration and interaction with non-human agents such as robots, animals too may be understood as potential collaborators under this umbrella. In light of evidence

Dimension	**SensorySafari**	**CreatureConnect**
System architecture	With two independent devices, the lemurs and humans cannot affect each other's interactions	With two synchronous devices, lemurs and humans can affect each other's interactions
Interaction mode	Lemurs activate the system by approaching it	Lemurs' proximity alters stimulus intensity
The system's purpose for visitors	Zoo visitors play a game, guessing lemurs' preferences	Visitors adjust intensity levels via a slider to affect each stimulus in the joint system
Stimulus selection	Zoo visitors can choose to trigger either unimodal or multimodal stimuli The selection between multimodal and unimodal stimuli for lemurs is made at random	The system presents bimodal stimuli randomly for both lemurs and visitors Bimodal stimuli for lemurs get selected randomly
Control distribution	Neither party controls the intensity No party is designated as controlling the system	There are four distinct control settings The visitor and/or lemur can exercise control
Transparency of lemur behaviour	The device screen shows the lemur's sensory preferences, and zoo visitors can observe the lemur's system use	Zoo visitors can directly observe how lemurs use the device via video feeds on both the visitors' and lemurs' screens.

Table 11: Comparison of the methods behind *SensorySafari* and *CreatureConnect*.

that animal communication reflects social context [109], digital systems should incorporate support for animals' social contexts rather than isolate them [66]. Moreover, our findings suggest that cross-species systems should enable forms of collaboration that treat animals as equal partners rather than passive recipients. Related ethics considerations, accordingly, must centre on how technology establishes and mediates the shared social context within which non-human primates as participants and humans collaborate across their divide. That context has to support voluntary engagement and disengagement, and it must minimise disruption. Our work is not an attempt to redefine 'collaboration' but an illustration of extending the boundaries of participation through technology-afforded interaction. Widening the scope beyond humans to robots, animals, and even other agents casts light on technology's special value and potential in fostering mutual understanding and social interaction among diverse users.

8 LIMITATIONS AND FUTURE WORK

Our study offers evidence of how control's allocation between red-ruffed lemurs and human visitors affects both groups in a zoo setting. Future work should extend such consideration across diverse sites, species, climates, and cultural contexts to examine how the distribution of control can nurture more mutually beneficial cross-species interaction. While our study spanned 20 days, longer-term experiments are needed to investigate how control-related conditions sustain animal engagement and whether animals can perceive, locate, and learn from control mechanisms, such that enrichment for both animals and humans benefits. Additionally, while control is dynamic and multi-dimensional, this early study did not isolate parameters such as stimulus intensity, interaction timing, and interaction mode, each of which may align in its own way with species-specific cognitive capacities. Future studies could explore these dimensions.

While our study did not examine whether red-ruffed lemurs show overuse, additional work could clarify what repetitive use or addiction-like interaction might mean in animal–technology contexts and how to design against excessive interaction while still supporting animals' enrichment. On the human side, future work could examine intentions – e.g., to support conservation or make donations [110]. Work with orangutans has found a link between education effects and increased donation behaviour [92], indicating a relevant avenue that our study did not follow. Also, we did not consider zookeepers' interactions within the system architecture, but future work could involve the staff as users of the system. Finally, our measurements focused on animals' observable engagement rather than on internal markers, such as cortisol levels. While these are not definitive indicators of animal welfare, follow-on work could incorporate behavioural and physiological metrics to enable richer, more holistic assessment of animal welfare.

9 CONCLUSIONS

Technologies hold vast opportunities to enhance animal–visitor interactions at zoos by allowing the two parties to interact appropriately via computer systems. We demonstrated this by developing and testing *CreatureConnect*. Most tellingly, implementing this shared-control system for mutual interaction revealed that giving red-ruffed lemurs total control over interactive systems did not yield cumulative benefits. Hence, joint control by humans and animals stands out as a dynamic, interactive process able to reveal how different species engage with shared technologies. By extending computer-supported collaborative systems to include non-human actors, our work contributes new insight related to shared agency in ACI and HCI design both. In demonstrating that optimal outcomes require balancing control rather than maximising it for any single participant, this research provides a starting point for design principles and fuller understanding of how control may be distributed across individuals with varying sensory preferences and interaction approaches.

ACKNOWLEDGMENTS

We wish to thank Blair Drummond Safari Park and Zoo, the lemurs, and their keepers for their participation and support.

REFERENCES

[1] Association of Zoos and Aquariums. 2023. Accreditation Standards and Related Policies. https://www.aza.org/assets/2332/aza-accreditation-standards.pdf. Retrieved September 8, 2025.

[2] Association of Zoos and Aquariums. 2024. About Us. https://www.aza.org/about-us. Retrieved June 24, 2024.

[3] Inbal Badihi. 2006. *The Effects of Complexity, Choice and Control on the Behaviour and the Welfare of Captive Common Marmosets (Callithrix jacchus).* PhD thesis. University of Stirling. http://hdl.handle.net/1893/120 Retrieved September 9, 2025.

[4] Lois Bassett and Hannah M. Buchanan-Smith. 2007. Effects of Predictability on the Welfare of Captive Animals. *Applied Animal Behaviour Science* 102, 3-4 (2007), 223–245. https://doi.org/10.1016/j.applanim.2006.05.029

[5] Dan Bennett, Oussama Metatla, Anne Roudaut, and Elisa D. Mekler. 2023. How Does HCI Understand Human Agency and Autonomy?. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 375, 18 pages. https://doi.org/10.1145/3544548.3580651

[6] Elena Bersacola, Kimberley J. Hockings, Mark E. Harrison, Muhammad Ali Imron, Joana Bessa, Marina Ramon, Aissa Regalla de Barros, Maimuna Jaló, Américo Sanhá, and Carlos R. Ruiz-Miranda. 2023. Primate Conservation in Shared Landscapes. In *Primates in Anthropogenic Landscapes: Exploring Primate Behavioural Flexibility Across Human Contexts*, T. McKinney, S. Waters, and M. A. Rodrigues (Eds.). Springer International Publishing, Cham, 161–181. https://doi.org/10.1007/978-3-031-11736-7_10

[7] Tammie L. Bettinger, Katherine A. Leighty, Rachel B. Daneault, Elizabeth A. Richards, and Joseph T. Bielitzki. 2017. Behavioral Management: The Environment and Animal Welfare. In *Handbook of Primate Behavioral Management*, Steven J. Schapiro (Ed.). CRC Press, Boca Raton, FL, USA, 37–51. https://doi.org/10.1201/9781315120652-4

[8] Barbara Blakeslee and Gerald H. Jacobs. 1985. Color Vision in the Ring-Tailed Lemur (Lemur catta). *Brain, Behavior and Evolution* 26, 3-4 (1985), 154–166. https://doi.org/10.1159/000118772

[9] Susanne Bødker. 2015. Third-Wave HCI, 10 Years Later—Participation and Sharing. *interactions* 22, 5 (2015), 24–31. https://doi.org/10.1145/2804405

[10] Cortni Borgerson, Timothy M. Eppley, Erik R. Patel, Steig Johnson, Edward E. Jr. Louis, and Jonah Razafindramanana. 2020. Red Ruffed Lemur (Varecia rubra). https://doi.org/10.2305/IUCN.UK.2020-2.RLTS.T22920A115574598.en

[11] Sabrina Brando and Hannah M. Buchanan-Smith. 2018. The 24/7 Approach to Promoting Optimal Welfare for Captive Wild Animals. *Behavioural Processes* 156 (2018), 83–95. https://doi.org/10.1016/j.beproc.2017.09.010

[12] Stephen Brewster, David McGookin, and Christopher Miller. 2006. Olfoto: designing a smell-based interaction. In *Proceedings of the SIGCHI conference on Human Factors in computing systems.* Association for Computing Machinery, New York, NY, USA, 653–662. https://doi.org/10.1145/1124772.1124869

[13] Adam Britt. 1998. Encouraging Natural Feeding Behavior in Captive-Bred Black and White Ruffed Lemurs (*Varecia variegata variegata*). *Zoo Biology* 17, 5 (1998), 379–392. https://doi.org/10.1002/(SICI)1098-2361(1998)17:5<379::AID-ZOO3>3.0.CO;2-X

[14] Heather Browning and Walter Veit. 2025. Animal Welfare, Agency, and Animal–Computer Interaction. *Animals* 15, 2 (2025), 219. https://doi.org/10.3390/ani15020219

[15] Hannah M. Buchanan-Smith and Inbal Badihi. 2012. The Psychology of Control: Effects of Control over Supplementary Light on Welfare of Marmosets. *Applied Animal Behaviour Science* 137, 3-4 (2012), 166–174. https://doi.org/10.1016/j.applanim.2011.07.002

[16] Minghao Cai and Jiro Tanaka. 2019. Go Together: Providing Nonverbal Awareness Cues to Enhance Co-Located Sensation in Remote Communication. *Human-Centric Computing and Information Sciences* 9, 1 (2019), 19. https://doi.org/10.1186/s13673-019-0180-y

[17] Marcus Carter, Sarah Webber, and Sally Sherwen. 2015. Naturalism and ACI: augmenting zoo enclosures with digital technology. In *Proceedings of the 12th International Conference on Advances in Computer Entertainment Technology.* Association for Computing Machinery (ACM), Iskandar, Malaysia, 1–5. https://doi.org/10.1145/2832932.2837011

[18] Techin Chantarachai. 2024. *Flavor extraction from dried lavender flower lavandula angustifolia by enfleurage method and its application in pasteurized milk.* Master's thesis. Chulalongkorn University. https://doi.org/10.58837/CHULA.THE.2024.270

[19] Aihui Chen, Yaobin Lu, and Bin Wang. 2016. Enhancing Perceived Enjoyment in Social Games through Social and Gaming Factors. *Information Technology & People* 29, 1 (2016), 99–119. https://doi.org/10.1108/ITP-07-2014-0156

[20] Gabriele Cimolino, Sussan Askari, and T. C. Nicholas Graham. 2021. The Role of Partial Automation in Increasing the Accessibility of Digital Games. *Proceedings of the ACM on Human-Computer Interaction* 5, CHI PLAY, Article 221 (2021), 30 pages. https://doi.org/10.1145/3474693

[21] Gabriele Cimolino and T. C. Nicholas Graham. 2022. Two Heads Are Better Than One: A Dimension Space for Unifying Human and Artificial Intelligence in Shared Control. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems.* Association for Computing Machinery, New York, NY, USA, 1–21. https://doi.org/10.1145/3491102.3517610

[22] Anna M Claxton. 2011. The potential of the human–animal relationship as an environmental enrichment for the welfare of zoo-housed animals. *Applied Animal Behaviour Science* 133, 1-2 (2011), 1–10. https://doi.org/10.1016/j.applanim.2011.03.002

[23] Amanda W. Clay, Bonnie M. Perdue, Diann E. Gaalema, Francine L. Dolins, and Mollie A. Bloomsmith. 2011. The use of technology to enhance zoological parks. *Zoo Biology* 30, 5 (2011), 487–497. https://doi.org/10.1002/zoo.20353

[24] Jon Coe. 2017. Embedding Environmental Enrichment into Zoo Animal Facility Design. In *Proceedings of the Zoodesign Conference 2017, Wroclaw, Poland.* Zoodesign Conference, Wroclaw, Poland, 5–7. https://zoolex.org/media/uploads/2018/07/29/coe_keynote.pdf

[25] Jon Coe and Julia Hoy. 2020. Choice, Control and Computers: Empowering Wildlife in Human Care. *Multimodal Technologies and Interaction* 4, 4 (2020), 92. https://doi.org/10.3390/mti4040092

[26] Jennifer Cunha, Corinne C. Renguette, Nikhil Singh, Lily Stella, Megan Mcmahon, Hao Jin, and Rebecca Kleinberger. 2024. Ellie Talks About the Weather: Toward Evaluating the Expressive and Enrichment Potential of a Tablet-Based Speech Board in a Single Goffin's Cockatoo. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems.* Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3613904.3643654

[27] Neil D'Cruze, Sophie Khan, Gemma Carder, David Megson, Emma Coulthard, John Norrey, and Georgina Groves. 2019. A Global Review of Animal–Visitor Interactions in Modern Zoos and Aquariums and Their Implications for Wild Animal Welfare. *Animals* 9, 6 (2019), 332. https://doi.org/10.3390/ani9060332

[28] Chiara De Gregorio, Daria Valente, Teresa Raimondi, Valeria Torti, Longondraza Miaretsoa, Olivier Friard, Cristina Giacoma, Andrea Ravignani, and Marco Gamba. 2021. Categorical rhythms in a singing primate. *Current Biology* 31, 20 (2021), R1379–R1380. https://doi.org/10.1016/j.cub.2021.09.032

[29] Neil D'Cruze and Georgina Groves. 2024. Animal–Visitor Interactions. In *Human-Animal Interactions in Zoos: Integrating Science and Practice.* CABI, Wallingford, Oxfordshire, UK, 16–32. https://doi.org/10.1079/9781800622715.0003

[30] Jan M. Engelmann, Esther Herrmann, Marina Proft, Stefanie Keupp, Yarrow Dunham, and Hannes Rakoczy. 2022. Chimpanzees Consider Freedom of Choice in Their Evaluation of Social Action. *Biology Letters* 18, 2 (2022), 20210502. https://doi.org/10.1098/rsbl.2021.0502

[31] Maisy D. Englund and Katherine A. Cronin. 2023. Choice, Control, and Animal Welfare: Definitions and Essential Inquiries to Advance Animal Welfare Science. *Frontiers in Veterinary Science* 10 (2023), 1250251. https://doi.org/10.3389/fvets.2023.1250251

[32] Gonzalo Erdozain. 2013. *Best Practices for Designing and Planning Events Where Human–Animal Interactions Are Encouraged, Based on Observations of Risk Behaviors and Hand Hygiene at Such Events.* Master of Public Health thesis. Kansas State University, Manhattan, Kansas. https://krex.k-state.edu/items/dd96bc5c-7f15-4ead-876d-20ea5d1d4250 Retrieved September 9, 2025.

[33] Joël Fagot and Élodie Bonté. 2010. Automated Testing of Cognitive Performance in Monkeys: Use of a Battery of Computerized Test Systems by a Troop of Semi-Free-Ranging Baboons (Papio papio). *Behavior Research Methods* 42, 2 (2010), 507–516. https://doi.org/10.3758/BRM.42.2.507

[34] Eduardo J. Fernandez and Sally L. Sherwen (Eds.). 2024. *Human–Animal Interactions in Zoos: Integrating Science and Practice.* CABI, Wallingford, UK. https://doi.org/10.1079/9781800622715.0000

[35] Raghavendra Gadagkar. 2021. How to Design Experiments in Animal Behaviour: 16. Cutting-Edge Research at Trifling Cost. *Resonance* 26 (2021), 105–125. https://doi.org/10.1007/s12045-020-1108-6

[36] Marco Gamba, Valeria Torti, Vittoria Estienne, Rose M Randrianarison, Daria Valente, Paolo Rovara, Giovanna Bonadonna, Olivier Friard, and Cristina Giacoma. 2016. The indris have got rhythm! Timing and pitch variation of a primate song examined between sexes and age classes. *Frontiers in Neuroscience* 10 (2016), 249. https://doi.org/10.3389/fnins.2016.00249

[37] Elias Garcia-Pelegrin. 2025. Do Robots Belong in Zoos? *Biological Conservation* 309 (Sept. 2025), 111293. https://doi.org/10.1016/j.biocon.2025.111293

[38] Anne E. Goodenough, Katie McDonald, Kayleigh Moody, and Clare Wheeler. 2019. Are "Visitor Effects" Overestimated? Behaviour in Captive Lemurs Is Mainly Driven by Co-Variation with Time and Weather. *Journal of Zoo and Aquarium Research* 7, 2 (April 2019), 59–66. https://doi.org/10.19227/jzar.v7i2.343

[39] Matt Gottsacker, Nels Numan, Anthony Steed, Gerd Bruder, Gregory F. Welch, and Steven Feiner. 2025. Decoupled Hands: An Approach for Aligning Perspectives in Collaborative Mixed Reality. In *Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–7. https://doi.org/10.1145/3706599.3720219

[40] Alana Grant, Vilma Kankaanpää, and Ilyena Hirskyj-Douglas. 2023. Humble Beginnings: Developing Touch-and Proximity-Input-Based Interfaces for Zoo-Housed Giraffes' Audio Enrichment. *Proceedings of the ACM on Human-Computer Interaction* 7, ISS (2023), 175–197. https://doi.org/10.1145/3626470

[41] Barry G. Green, Pamela Dalton, Beverly Cowart, Greg Shaffer, Krystyna Rankin, and Jennifer Higgins. 1996. Evaluating the 'Labeled Magnitude Scale' for Measuring Sensations of Taste and Smell. *Chemical Senses* 21, 3 (1996), 323–334. https://doi.org/10.1093/chemse/21.3.323

[42] Madeleine Hansell, Angelica Åsberg, and Matthias Laska. 2020. Food Preferences and Nutrient Composition in Zoo-Housed Ring-Tailed Lemurs (*Lemur catta*). *Physiology & Behavior* 226 (2020), 113125. https://doi.org/10.1016/j.physbeh.2020.113125

[43] Donna Haraway. 2024. When Species Meet. In *The Routledge International Handbook of More-than-Human Studies*, Adrian Franklin (Ed.). Routledge, London and New York, 42–78. https://doi.org/10.4324/9781003262619-4

[44] Lilliana Hassinger and Christena Nippert-Eng. 2025. Beyond the Camera Trap: A Systematic Review of Computing Technology Used to Monitor and Interact with (More) Varied Taxa in Zoos and Aquariums. *Animals* 15, 12 (2025), 1721. https://doi.org/10.3390/ani15121721

[45] Ilyena Hirskyj-Douglas and Vilma Kankaanpää. 2021. Exploring how white-faced sakis control digital visual enrichment systems. *Animals* 11, 2 (2021), 557. https://doi.org/10.3390/ani11020557

[46] Ilyena Hirskyj-Douglas and Vilma Kankaanpää. 2022. Do Monkeys Want Audio or Visual Stimuli? Interactive Computers for Choice with White-Faced Sakis in Zoos. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference (DIS '22)*. Association for Computing Machinery, New York, NY, USA, 1497–1511. https://doi.org/10.1145/3532106.3533577

[47] Ilyena Hirskyj-Douglas and Andrés Lucero. 2019. On the Internet, Nobody Knows You're a Dog... Unless You're Another Dog. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery (ACM), New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300347

[48] Ilyena Hirskyj-Douglas, Patricia Pons, Janet C Read, and Javier Jaen. 2018. Seven years after the manifesto: Literature review and research directions for technologies in animal computer interaction. *Multimodal Technologies and Interaction* 2, 2 (2018), 30. https://doi.org/10.3390/mti2020030

[49] Lindsay A. Hogan, Stephen D. Johnston, Allan T. Lisle, Tamara Keeley, Phoenix Wong, Vere Nicolson, Alan B. Horsup, Tina Janssen, and Clive J. C. Phillips. 2011. Behavioural and Physiological Responses of Captive Wombats (*Lasiorhinus latifrons*) to Regular Handling by Humans. *Applied Animal Behaviour Science* 134, 3–4 (2011), 217–228. https://doi.org/10.1016/j.applanim.2011.07.010

[50] Kasper Hornbæk and Antti Oulasvirta. 2017. What Is Interaction?. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 5040–5052. https://doi.org/10.1145/3025453.3025765

[51] Geoff Hosey and Vicky Melfi. 2015. Are We Ignoring Neutral and Negative Human–Animal Relationships in Zoos? *Zoo Biology* 34, 1 (2015), 1–8. https://doi.org/10.1002/zoo.21182

[52] Lilly Irani, Janet Vertesi, Paul Dourish, Kavita Philip, and Rebecca E. Grinter. 2010. Postcolonial Computing: A Lens on Design and Development. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1311–1320. https://doi.org/10.1145/1753326.1753522

[53] Gerald H Jacobs. 1996. Primate photopigments and primate color vision. *Proceedings of the National Academy of Sciences* 93, 2 (1996), 577–581. https://doi.org/10.1073/pnas.93.2.577

[54] Rachel L Jacobs, Carrie C Veilleux, Edward E Louis Jr, James P Herrera, Chihiro Hiramatsu, David C Frankel, Mitchell T Irwin, Amanda D Melin, and Brenda J Bradley. 2019. Less is more: lemurs (Eulemur spp.) may benefit from loss of trichromatic vision. *Behavioral Ecology and Sociobiology* 73, 2 (2019), 22. https://doi.org/10.1007/s00265-018-2629-9

[55] Ellesse D Janda, Kate L Perry, Emma Hankinson, David Walker, and Stefano Vaglio. 2019. Sex differences in scent-marking in captive red-ruffed lemurs. *American Journal of Primatology* 81, 1 (2019), e22951. https://doi.org/10.1002/ajp.22951

[56] Hayley Jones, Peter K. McGregor, Holly L. Farmer, and Kathy Rose Baker. 2016. The influence of visitor interaction on the behavior of captive crowned lemurs (Eulemur coronatus) and implications for welfare. *Zoo Biology* 35, 3 (2016), 222–227. https://doi.org/10.1002/zoo.21291

[57] Cécile Juan, Céline Cappe, Baptiste Alric, Benoît Roby, Sophie Gilardeau, Pascal Barone, and Pascal Girard. 2017. The variability of multisensory processes of natural stimuli in human and non-human primates in a detection task. *PLOS ONE* 12, 2 (2017), e0172480. https://doi.org/10.1371/journal.pone.0172480

[58] Vimal V. Kamadia, Youngmo Yoon, Mark W. Schilling, and Douglas L. Marshall. 2006. Relationships between odorant concentration and aroma intensity. *Journal of Food Science* 71, 3 (2006), S193–S197. https://doi.org/10.1111/j.1365-2621.2006.tb15640.x

[59] Juliane Kaminski. 2011. Communicative cues among and between human and non-human primates: attending to specificity in triadic gestural interactions. In *Coordination in Human and Primate Groups*, M. Boos, M. Kolbe, P. Kappeler, and T. Ellwart (Eds.). Springer, Berlin, Germany, 245–261. https://doi.org/10.1007/978-3-642-15355-6_14

[60] Vilma Kankaanpää, Fay E. Clark, and Ilyena Hirskyj-Douglas. 2024. Lemur-Lounge: Lemurs' Individual-Level, Group, and Cross-Species Use of an Interactive Audio Device in Zoos. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA). Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3613904.3641888

[61] Vilma Kankaanpää and Ilyena Hirskyj-Douglas. 2023. Prototyping with Monkeys: Uncovering What Buttons for Monkeys Look Like. In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (Warsaw, Poland) *(TEI '23)*. Association for Computing Machinery, New York, NY, USA, Article 4, 13 pages. https://doi.org/10.1145/3569009.3572735

[62] Soheil Kianzad, Yuxiang Huang, Robert Xiao, and Karon E. MacLean. 2020. Phasking on Paper: Accessing a Continuum of Physically Assisted Sketching. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3313831.3376134

[63] Klara Kittler, Peter M Kappeler, and Claudia Fichtel. 2018. Instrumental problem-solving abilities in three lemur species (Microcebus murinus, Varecia variegata, and Lemur catta). *Journal of Comparative Psychology* 132, 3 (2018), 306. https://doi.org/10.1037/com0000113

[64] Rachel Kleinberger. 2023. Sonic enrichment at the zoo: What will the zoo of the future sound like? *Interaction Studies* 24, 2 (2023), 257–288. https://doi.org/10.1075/is.22026.kle

[65] Rebecca Kleinberger, Lena Ashooh, Keavan Farsad, and Ilyena Hirskyj-Douglas. 2025. Animals' Entanglement with Technology: A Scoping Review. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–22. https://doi.org/10.1145/3706598.3713384

[66] Reébecca Kleinberger, Anne HK Harrington, Lydia Yu, Akito Van Troyer, David Su, Janet M. Baker, and Gabriel Miller. 2020. Interspecies interactions mediated by technology: An avian case study at the zoo. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3313831.3376858

[67] Marni LaFleur, Tara A Clarke, Kim Reuter, and Toby Schaeffer. 2017. Rapid decrease in populations of wild ring-tailed lemurs (Lemur catta) in Madagascar. *Folia Primatologica* 87, 5 (2017), 320–330. https://doi.org/10.1159/000455121

[68] Kevin N Ochsner Lauren A Leotti, Sheena S Iyengar. 2010. Born to choose: the origins and value of the need for control. *Trends in Cognitive Sciences* 14, 10 (2010), 457–463. https://doi.org/10.1016/j.tics.2010.08.001

[69] David A. Leavens, Filippo Aureli, William D. Hopkins, and Charles W. Hyatt. 2001. Effects of cognitive challenge on self-directed behaviors by chimpanzees (Pan troglodytes). *American Journal of Primatology* 55, 1 (2001), 1–14. https://doi.org/10.1002/ajp.1034

[70] Patrick Lecomte. 2023. Umwelt as the foundation of an ethics of smart environments. *Humanities and Social Sciences Communications* 10, 1 (2023), 23:356. https://doi.org/10.1057/s41599-023-02356-9

[71] Sara Diana Leonhardt, Jenny Tung, J. B. Camden, Manuel Leal, and Christine M. Drea. 2009. Seeing red: behavioral evidence of trichromatic color vision in strepsirrhine primates. *Behavioral Ecology* 20, 1 (2009), 1–12. https://doi.org/10.1093/beheco/arn106

[72] Kate E. Littin and David J. Mellor. 2005. Strategic animal welfare issues: ethical and animal welfare issues arising from the killing of wildlife for disease control and environmental reasons. *Revue Scientifique et Technique* 24, 2 (2005), 767–782. http://www.oie.int/doc/en_document.php?numrec=3326803

[73] Jerry F Luebke. 2018. Zoo exhibit experiences and visitors' affective reactions: A preliminary study. *Curator: the museum journal* 61, 2 (2018), 345–352. https://doi.org/10.1111/cura.12253

[74] André De Sousa Machado, Francisco Sousa, Ana Silva, Luís Meireles, and André Sousa-Machado. 2023. Visual Analog Scale and Olfactory Objective Tests in Hyposmia Patients: Is There a Link? *Cureus* 15, 2 (2023), e35053. https://doi.org/10.7759/cureus.35053

[75] Clara Mancini. 2011. Animal-computer Interaction: A Manifesto. interactions 18, 4: 69–73. *Google Scholar Google Scholar Digital Library Digital Library* 4 (2011), 69–73. https://doi.org/10.1145/1978822.1978836

[76] Clara Mancini. 2017. Towards an animal-centred ethics for Animal–Computer Interaction. *International Journal of Human-Computer Studies* 98 (2017), 221–233. https://doi.org/10.1016/j.ijhcs.2016.04.008

[77] Christopher Flynn Martin, Rahul Bhui, Peter Bossaerts, Tetsuro Matsuzawa, and Colin Camerer. 2014. Chimpanzee choice rates in competitive games match equilibrium game theory predictions. *Scientific reports* 4, 1 (2014), 5182. https://doi.org/10.1038/srep05182

[78] Christopher Flynn Martin, Dora Biro, and Tetsuro Matsuzawa. 2017. Chimpanzees spontaneously take turns in a shared serial ordering task. *Scientific Reports* 7, 1 (2017), 14307. https://doi.org/10.1038/s41598-017-14393-x

[79] Christopher Flynn Martin and Robert W. Shumaker. 2018. Computer tasks for great apes promote functional naturalism in a zoo setting. In *Proceedings of the Fifth International Conference on Animal-Computer Interaction (ACI '18)*. Association for Computing Machinery, New York, NY, USA, 1–5. https://doi.org/10.1145/3295598.3295605

[80] Josh McDermott and Marc D. Hauser. 2007. Nonhuman primates prefer slow tempos but dislike music overall. *Cognition* 104, 3 (2007), 654–668. https://doi.org/10.1016/j.cognition.2006.07.011

[81] Emily M. McLeod, Kelly S. Fielding, and Angela J. Dean. 2024. Understanding and Improving the Visitor Experience: How Can We Increase the Positive Social Impact of Animal–Visitor Interactions? In *Human-Animal Interactions in Zoos: Integrating Science and Practice*. CABI, Wallingford, Oxfordshire, UK, 192–204. https://doi.org/10.1079/9781800622715.0014

[82] Xavier McNally, Thomas L. Webb, Charlotte Smith, Andrew Moss, and Jilly Gibson-Miller. 2025. A meta-analysis of the effect of visiting zoos and aquariums on visitors' conservation knowledge, beliefs, and behavior. *Conservation Biology* 39, 1 (2025), e14237. https://doi.org/10.1111/cobi.14237

[83] D. J. Mellor. 2015. Enhancing animal welfare by creating opportunities for positive affective engagement. *New Zealand Veterinary Journal* 63, 1 (2015), 3–8. https://doi.org/10.1080/00480169.2014.926799

[84] Merriam-Webster. 2023. Choice. https://www.merriam-webster.com/dictionary/choice Accessed: July 31, 2025.

[85] Ádám Miklósi. 2014. *Dog behaviour, evolution, and cognition* (2 ed.). Oxford University Press, Oxford, UK. https://doi.org/10.1093/acprof:oso/9780199295852.001.0001

[86] Tom P. Moorhouse, Cecilia A. L. Dahlsjö, Sandra E. Baker, Neil C. D'Cruze, and David W. Macdonald. 2015. The customer isn't always right: conservation and animal welfare implications of the increasing demand for wildlife tourism. *PLOS ONE* 10, 10 (2015), e0138939. https://doi.org/10.1371/journal.pone.0138939

[87] Andrew Moss, Eric Jensen, and Markus Gusset. 2014. Conservation: Zoo visits boost biodiversity literacy. *Nature* 508, 7495 (2014), 186. https://doi.org/10.1038/508186d

[88] Donald A. Norman. 1988. *The Psychology of Everyday Things*. Basic Books, New York, NY, USA. https://psycnet.apa.org/record/1988-97561-000

[89] Tadatoshi Ogura. 2012. Use of video system and its effects on abnormal behaviour in captive Japanese macaques (*Macaca fuscata*). *Applied Animal Behaviour Science* 141, 3–4 (2012), 173–183. https://doi.org/10.1016/j.applanim.2012.06.009

[90] Anna Oleszkiewicz, Rafieh Alizadeh, Aytug Altundag, Ben Chen, Alessandra Corrai, Rachele Fanari, Mohammad Farhadi, Neelima Gupta, Rebecca Habel, Robyn Hudson, Jessica L. Hughes, Akshita Joshi, Seyed Kamran Kamrava, Curtis Luckett, Mehmet K. Mahmut, Carla Masala, Eri Mori, Robert Pellegrino, Raffaella Piras, Katarzyna Resler, Alejandro Rivas-Castro, Supreet Saluja, Sanskriti Sharma, Hajime Shimmura, Graciela M. Soler, Michał Mikołaj Stefańczyk, Zhifu Sun, Divesh Thaploo, Yongxiang Wei, Xiaoguang Yan, and Thomas Hummel. 2020. Global study of variability in olfactory sensitivity. *Behavioral Neuroscience* 134, 5 (2020), 394. https://doi.org/10.1037/bne0000378

[91] Patricia Patrick, Cathy Mathews, and Sue Dale Tunnicliffe. 2013. Using a field trip inventory to determine if listening to elementary school students' conversations, while on a zoo field trip, enhances preservice teachers' abilities to plan zoo field trips. *International Journal of Science Education* 35, 15 (2013), 2645–2669. https://doi.org/10.1080/09500693.2011.620035

[92] Elissa L Pearson, Rachel Lowry, Jillian Dorrian, and Carla A Litchfield. 2014. Evaluating the conservation impact of an innovative zoo-based educational campaign:'Don't Palm Us Off'for orang-utan conservation. *Zoo biology* 33, 3 (2014), 184–196. https://doi.org/10.1002/zoo.21120

[93] Roosa Piitulainen and Ilyena Hirskyj-Douglas. 2020. Music for monkeys: building methods to design with white-faced sakis for animal-driven audio enrichment devices. *Animals* 10, 10 (2020), 1768. https://doi.org/10.3390/ani10101768

[94] Jorge A Pino, Judith Mesa, Yamilie Muñoz, M Pilar Martí, and Rolando Marbot. 2005. Volatile components from mango (Mangifera indica L.) cultivars. *Journal of Agricultural and Food Chemistry* 53, 6 (2005), 2213–2223. https://doi.org/10.1021/jf0402633

[95] Ilaria Pollastri, Simona Normando, Daniela Florio, Linda Ferrante, Francesca Bandoli, Elisabetta Macchi, Alessia Muzzo, and Barbara de Mori. 2022. The Animal-Visitor Interaction Protocol (AVIP) for the assessment of *Lemur catta* walk-in enclosure in zoos. *PLOS ONE* 17, 7 (2022), e0271409. https://doi.org/10.1371/journal.pone.0271409

[96] Mark S. Rea, Mariana G. Figueiro, Geoffrey E. Jones, and Kenneth E. Glander. 2014. Daily activity and light exposure levels for five species of lemurs at the Duke Lemur Center. *American Journal of Physical Anthropology* 153, 1 (2014), 68–77. https://doi.org/10.1002/ajpa.22409

[97] Pamela J. Reid. 2009. Adapting to the human world: dogs' responsiveness to our social cues. *Behavioural Processes* 80, 3 (2009), 325–333. https://doi.org/10.1016/j.beproc.2008.11.002

[98] Stanley Ries, Rebecca Baughan, Muraleedharan G. Nair, and Robert Schutzki. 2001. Repelling animals from crops using plant extracts. *HortTechnology* 11, 2 (2001), 302–307. https://doi.org/10.21273/HORTTECH.11.2.302

[99] Sarah E Ritvo and Robert S Allison. 2014. Challenges related to nonhuman animal-computer interaction: Usability and 'liking'. In *Proceedings of the 2014 Workshops on Advances in Computer Entertainment Conference*. ACM, Funchal, Portugal, 1–7. https://doi.org/10.1145/2693787.2693795

[100] Lindsey Robbins and Susan W Margulis. 2014. The effects of auditory enrichment on gorillas. *Zoo biology* 33, 3 (2014), 197–203. https://doi.org/10.1002/zoo.21127

[101] Charlotte Robinson, Clara Mancini, Janet van der Linden, Claire Guest, Lydia Swanson, Helen Marsden, Jose Valencia, and Brendan Aengenheister. 2015. Designing an emergency communication system for human and assistance dog partnerships. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Osaka, Japan) *(UbiComp '15)*. Association for Computing Machinery, New York, NY, USA, 337–347. https://doi.org/10.1145/2750858.2805849

[102] Paul E Rose and Lisa M Riley. 2022. Expanding the role of the future zoo: Wellbeing should become the fifth aim for modern zoos. *Frontiers in Psychology* 13 (2022), 1018722. https://doi.org/10.3389/fpsyg.2022.1018722

[103] Luisa Ruge, Elizabeth Cox, Clara Mancini, and Rachael Luck. 2018. User Centered Design Approaches to Measuring Canine Behavior: Tail Wagging as a Measure of User Experience. In *Proceedings of the Fifth International Conference on Animal-Computer Interaction (ACI '18)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3295598.3295599

[104] Julie Rushmore, Sara D. Leonhardt, and Christine M. Drea. 2012. Sight or Scent: Lemur Sensory Reliance in Detecting Food Quality Varies with Feeding Ecology. *PLoS ONE* 7, 8 (2012), e41558. https://doi.org/10.1371/journal.pone.0041558

[105] Allison Sauppé and Bilge Mutlu. 2014. How Social Cues Shape Task Coordination and Communication. In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '14)*. Association for Computing Machinery, New York, NY, USA, 97–108. https://doi.org/10.1145/2531602.2531610

[106] Benjamin Scheer, Fidel Cano Renteria, and Maithilee Kunda. 2019. Technology-Based Cognitive Enrichment for Animals in Zoos: A Case Study and Lessons Learned. In *Proceedings of the 41st Annual Meeting of the Cognitive Science Society (CogSci 2019): Creativity + Cognition + Computation*. Cognitive Science Society, Montreal, QC, Canada, 2741–2747. https://escholarship.org/uc/item/6xq790f1

[107] Hanna Schneider, Malin Eiband, Daniel Ullrich, and Andreas Butz. 2018. Empowerment in HCI—A Survey and Framework. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3173574.3173818

[108] Elizabeth S. Scordato and Christine M. Drea. 2007. Scents and sensibility: information content of olfactory signals in the ring-tailed lemur, *Lemur catta*. *Animal Behaviour* 73, 2 (2007), 301–314. https://doi.org/10.1016/j.anbehav.2006.08.006

[109] Pratyusha Sharma, Shane Gero, Roger Payne, David F Gruber, Daniela Rus, Antonio Torralba, and Jacob Andreas. 2024. Contextual and combinatorial structure in sperm whale vocalisations. *Nature Communications* 15, 1 (2024), 3617. https://doi.org/10.1038/s41467-024-47221-8

[110] Jeffrey C Skibins and Robert B Powell. 2013. Conservation caring: Measuring the influence of zoo visitors' connection to wildlife on pro-conservation behaviors. *Zoo biology* 32, 5 (2013), 528–540. https://doi.org/10.1002/zoo.21086

[111] Patricia A Smiley. 2001. Intention understanding and partner-sensitive behaviors in young children's peer interactions. *Social Development* 10, 3 (2001), 330–354. https://doi.org/10.1111/1467-9507.00169

[112] Sarah Louise Spooner. 2017. *Evaluating the effectiveness of education in zoos.* Ph. D. Dissertation. University of York. https://etheses.whiterose.ac.uk/20370/

[113] Sarah L Spooner, Mark J Farnworth, Samantha J Ward, and Katherine M Whitehouse-Tedd. 2021. Conservation education: Are zoo animals effective ambassadors and is there any cost to their welfare? *Journal of Zoological and Botanical Gardens* 2, 1 (2021), 41–65.

[114] Kim-Pong Tam. 2013. Dispositional empathy with nature. *Journal of environmental psychology* 35 (2013), 92–104. https://doi.org/10.1016/j.jenvp.2013.05.004

[115] Emi Tamaki, Takashi Miyaki, and Jun Rekimoto. 2011. PossessedHand: Techniques for Controlling Human Hands Using Electrical Muscle Stimuli. In *Proceedings of the 29th Annual ACM Conference on Human Factors in Computing Systems (CHI '11)*. Association for Computing Machinery, New York, NY, USA, 543–552. https://doi.org/10.1145/1978942.1979018

[116] Jessie C. Tanner and Claire T. Hemingway. 2025. Choice overload and its consequences for animal decision-making. *Trends in Cognitive Sciences* 29, 5 (2025), 403–406. https://doi.org/10.1016/j.tics.2025.01.003

[117] Jenifer Tidwell. 2010. *Designing Interfaces: Patterns for Effective Interaction Design* (2nd ed.). O'Reilly Media, Inc., Sebastopol, CA, USA. https://www.google.co.uk/books/edition/Designing_Interfaces/5gvOU9X0fu0C?hl=en&gbpv=1

[118] Jordyn Truax and Jennifer Vonk. 2023. Silence is golden: Auditory preferences in zoo-housed gorillas. *Journal of Applied Animal Welfare Science* 26, 3 (2023), 404–419. https://doi.org/10.1080/10888705.2021.1968400

[119] Sue Dale Tunnicliffe. 2001. Talking about plants-comments of primary school groups looking at plant exhibits in a botanical garden. *Journal of Biological Education* 36, 1 (2001), 27–34. https://doi.org/10.1080/00219266.2001.9655792

[120] Edward Tunstel, Mark Maimone, Ashitey Trebi-Ollennu, Jeng Yen, Rich Petras, and Reg Willson. 2005. Mars Exploration Rover Mobility and Robotic Arm Operational Performance. In *2005 IEEE International Conference on Systems, Man, and Cybernetics (SMC'05)*, Vol. 2. IEEE, Waikoloa, HI, USA, 1807–1814. https://doi.org/10.1109/ICSMC.2005.1571410

[121] Jeremy G. Turner. 2020. Noise and vibration in the vivarium: recommendations for developing a measurement plan. *Journal of the American Association for Laboratory Animal Science* 59, 6 (2020), 665–672. https://doi.org/10.30802/AALAS-JAALAS-19-000131

[122] UK Government. 2025. Animal Welfare Rules in British Zoos Set for Major Overhaul. https://www.gov.uk/government/news/animal-welfare-rules-in-british-zoos-set-for-major-overhaul. Accessed: 2025-11-21.

[123] Frans van der Sluis, Betsy van Dijk, and Bert Perloy. 2012. Measuring fun and enjoyment of children in a museum: Evaluating the Smileyometer. In *Proceedings of measuring behavior*. Proceedings of measuring behavior, Wageningen, The Netherlands, 28–31. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2956298

[124] Natalie Vasey. 2004. Circadian rhythms in diet and habitat use in red ruffed lemurs (*Varecia rubra*) and white-fronted brown lemurs (*Eulemur fulvus albifrons*). *American Journal of Physical Anthropology* 124, 4 (2004), 353–363. https://doi.org/10.1002/ajpa.10357

[125] Urska Vrhovsek, Cesare Lotti, Domenico Masuero, Silvia Carlin, Georg Weingart, and Fulvio Mattivi. 2014. Quantitative metabolic profiling of grape, apple and raspberry volatile compounds (VOCs) using a GC/MS/MS method. *Journal of Chromatography B* 966 (2014), 132–139. https://doi.org/10.1016/j.jchromb.2014.01.009

[126] Corri Waitt and Hannah M Buchanan-Smith. 2006. Perceptual considerations in the use of colored photographic and video stimuli to study nonhuman primate behavior. *American Journal of Primatology: Official Journal of the American Society of Primatologists* 68, 11 (2006), 1054–1067. https://doi.org/10.1002/ajp.20303

[127] Jiaqi Wang, Stephen Anthony Brewster, and Ilyena Hirskyj-Douglas. 2025. Reshaping Human-Animal Relationships: Exploring Lemur and Human Enrichment through Smell, Sound, and Sight. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)* (Yokohama, Japan). Association for Computing Machinery, New York, NY, USA, 1–19. https://doi.org/10.1145/3706598.3713311

[128] Tamsin Elizabeth Ward-Smith and Murray Alan Potter. 1999. *Response of Wild Kiwi to Orange and Cinnamon Lured Possum Baits*. Technical Report 259. Department of Conservation, Wellington, New Zealand. 9 pages. https://www.doc.govt.nz/globalassets/documents/science-and-technical/casn259.pdf

[129] Sarah Webber, Marcus Carter, Sally Sherwen, Wally Smith, Zaher Joukhadar, and Frank Vetere. 2017. Kinecting with orangutans: Zoo visitors' empathetic responses to animals' use of interactive technology. In *Proceedings of the 2017 CHI conference on human factors in computing systems*. CHI'17, USA, 6075–6088. https://doi.org/10.1145/3025453.3025729

[130] Sarah Webber, Marcus Carter, Wally Smith, and Frank Vetere. 2017. Interactive technology and human–animal encounters at the zoo. *International Journal of Human-Computer Studies* 98 (2017), 150–168. https://doi.org/10.1016/j.ijhcs.2016.05.003

[131] Sarah Webber, Mia L. Cobb, and Jon Coe. 2022. Welfare through competence: a framework for animal-centric technology design. *Frontiers in Veterinary Science* 9 (2022), 885973. https://doi.org/10.3389/fvets.2022.885973

[132] Deborah L. Wells. 2009. Sensory stimulation as environmental enrichment for captive animals: A review. *Applied Animal Behaviour Science* 118, 1-2 (2009), 1–11. https://doi.org/10.1016/j.applanim.2009.02.007

[133] Deborah L. Wells and Rosie M. Irwin. 2008. Auditory stimulation as enrichment for zoo-housed Asian elephants (*Elephas maximus*). *Animal Welfare* 17, 4 (2008), 335–340. https://www.cambridge.org/core/journals/animal-welfare/article/abs/auditory-stimulation-as-enrichment-for-zoohoused-asian-elephants-elephas-maximus/1815F9B16054D4AEACFE49F24E9D65A8

[134] World Association of Zoos and Aquariums. 2023. WAZA Animal–Visitor Interaction Guidelines. https://www.waza.org/priorities/waza-code-of-ethics/waza-animal-visitor-interaction-guidelines/. Accessed: 2025-08-23.

[135] Yumi Yamanashi, Kazuki Hitoosa, Nobuaki Yoshida, Fumihiro Kano, Yuko Ikkatai, and Hidefusa Sakamoto. 2022. Do chimpanzees enjoy a virtual forest? A pilot investigation of the use of interactive art as a form of environmental enrichment for zoo-housed chimpanzees. *American Journal of Primatology* 84, 10 (2022), e23343. https://doi.org/10.1002/ajp.23343

[136] Uk-Hyeon Yeo, Cristina Decano-Valentin, Taehwan Ha, In-Bok Lee, Rack-Woo Kim, Sang-Yeon Lee, and Jun-Gyu Kim. 2020. Impact analysis of environmental conditions on odour dispersion emitted from pig house with complex terrain using CFD. *Agronomy* 10, 11 (2020), 1828. https://doi.org/10.3390/agronomy10111828

[137] Robert J. Young. 2003. *Environmental Enrichment for Captive Animals*. Wiley-Blackwell, Ames, IA, USA. 240 pages. https://www.wiley.com/en-us/Environmental%2BEnrichment%2Bfor%2BCaptive%2BAnimals-p-9780632064076

[138] Thomas R. Zentall. 2019. What Suboptimal Choice Tells Us About the Control of Behavior. *Comparative Cognition & Behavior Reviews* 14, 1 (2019), 1–17. https://doi.org/10.3819/CCBR.2019.140001