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Use of Interactive Technology in Captive Great Ape Management

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Abstract: The conservation status of great apes (chimpanzees *Pan troglodytes*, gorillas *Gorilla* sp., orangutans *Pongo* sp., and bonobos *Pan paniscus*) is grave and zoological institutions are vital for maintaining numbers of these species and educating the public about their importance. Technology provides tools that can assist zoos in meeting these objectives. However, the extant research on technology use in zoos is potentially constrained by small sample sizes and there is no framework detailing the methodologies necessary for the successful incorporation of technology into great ape management. Therefore, this study aimed to determine current technology use in the management of captive great apes and whether technology-directed behaviour differs between ape genera. Primary carers of great apes in zoos were surveyed using a 43-question, online questionnaire. The purpose of integrating interactive technology into captive ape management was primarily for enrichment (53% of respondents), followed by research (20% of respondents). However, only 25% of respondents had apes directly engaged with technology. There were no differences in technology-directed behaviours between ape genera. By identifying differences in practice, this research marks the initial stage in developing a best practice framework for using technology.

Keywords: great ape; conservation; zoo; management practices; interactive technology

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1. Introduction

Five of the seven great apes are listed as critically endangered (Western gorilla *Gorilla gorilla*, Eastern gorilla *Gorilla beringei*, Sumatran orangutan *Pongo abelii*, Bornean orangutan *Pongo pygmaeus*, and Tapanuli orangutan *Pongo tapanuliensis*), while the remaining two are endangered (chimpanzee *Pan troglodytes* and bonobo *Pan paniscus*) [1]. The grave conservation status of these great apes (hereafter referred to as apes) puts emphasis on the importance of successful captive holdings of these species [2]. Zoological institutions are instrumental in educating the public about these species and in turn raising money and support for their conservation. The Association of Zoos and Aquariums (AZA) promotes four overarching goals of modern zoos: an increase in animal welfare, enhancing public engagement, contributing to wildlife research, and improving wildlife conservation [3]. It is important to consider integrating technological tools into ape collections as they have the potential to help zoological institutions meet the goals of the AZA and zoological organisations globally [4]. For example, technology is used to improve animal welfare as it can increase control and choice for the captive apes and create more cognitively complex environments [5]. Animal research at zoological institutions can also incorporate technology to allow for non-invasive behavioural tests [6]. For example, accelerometers estimate body acceleration, global positioning system (GPS) tags monitor animal movements, and vocal behaviours can be measured using microphones [6]. Lastly, technology can improve visitor engagement and consequently public education [7].

The importance that the AZA and other zoo associations place on animal welfare is of significance as welfare can influence the success of the remaining goals [8]. The Zoos and Aquarium Association Australasia advocates for improvements in animal welfare in order to promote positive mental and physical experiences and decrease negative experiences and behaviours [9]. Welfare is decreased when an individual's cognitive abilities are understimulated and the environment lacks predictability or is too over predictable [10]. As a family, apes have advanced cognitive functioning in regard to spatial relations, causality and physical tasks [11–14]. For example, chimpanzees are known to use tools to extract underground nests of stingless bees [11], and orangutans have been observed exploring locations where food had been hidden two weeks prior [14]. Environmental enrichment is often incorporated into zoos to increase welfare [5,15,16] and has been defined as " . . . an animal husbandry principle that seeks to enhance the quality of captive animal care by identifying and providing the environmental stimuli necessary for optimal psychological and physiological well-being" [17] (p. 1). To meet the demands of these high cognitive skills, ape environmental enrichment must be varied, challenging, and flexible [18].

In the context of zoo enrichment, technology has been defined as "a form of environmental enrichment that presents cognitively engaging activities using [digital] devices, such as touchscreen monitors, iPads, or other devices" [5] (p. 4). This type of enrichment provides the apes with activities that engage their cognitive skills [15]. There are two broad categories that determine how an animal interacts with digital enrichment: (1) passive participation, for example, watching television, listening to music, or looking at digital photographs [5]; (2) active participation, which includes social interactions using technology. For example, video conference calls or multi-player games [5].

Microchip-automated technology is one form of technology that can be incorporated into the management of great apes to assist with research and husbandry practices. A microchip is a small implantable device, which is often used for identification or monitoring the behaviour and physiology of animals [19]. For example, microchip-activated nestboxes with cameras inside can be used to monitor nesting or breeding behaviours and the implanted devices can measure body temperature, which can be used as an indication of stress levels. This technology was originally developed for the management of livestock to improve ways in which individuals were rapidly identified (for example, by origin, age, and sex) and tracked throughout their life [20]. The success of this technology has led to its use in other fields, for example, in captive animal care and pet and wildlife monitoring [21–24]. Indeed, microchip-automated devices, such as doors and feeders are now both commercially available and affordable [23] and commonly used in pet care. This provides opportunities for their wider use in conservation research, particularly with captive-bred individuals [23]. For example, in less than 9 months, a wild-caught brush-tailed phascogale (*Phascogale tapoatafa*) successfully learnt to use microchip-automated doors and feeders, and the use of these devices remained effective one month later [22]. Similarly, a captive-bred bridled nailtail wallaby (*Onychogalea fraenata*) took 62 days to learn to use an automated door that led to a feeding pen [23]. The advantages of using microchip technology in conservation research include the reduction in animal–human contact; the accuracy and reliability of data collection and storage; and the permanence of the device [22,23]. Therefore, technology has the potential to better manage individuals in captivity, for example, controlling access to space and the provision of individual enrichment, food, or medication [21,22].

Visitor interaction with zoo exhibits plays a large role in determining the success of zoos in meeting their aim of public engagement, and technology can be used to influence visitors' attitudes, knowledge, and behaviour [25], which in turn impacts on conservation efforts [26]. Zoological institutions hold a pivotal role in educating the public, and therefore improvement in the methods by which zoos communicate with the public is likely to be beneficial [26]. However, this topic is beyond the scope of this paper as our research focuses on ape engagement with technology. We note, however, that ape–technology interactions in exhibits could have the potential to increase visitor engagement.

As technology has become more affordable and accessible [27], it is opportune to consider its diverse use in zoological institutions globally. There has been little research conducted on the use of technology in captive ape management and hence there is little guidance for institutions seeking to implement technology in their facilities. By collating a preliminary understanding of how zoos currently implement technology with reference to captive ape management it is likely that opportunities can be identified for others to benefit from existing user experiences. This research will contribute to the development of guidelines on appropriate methods of fostering ape–technology interactions in captive environments, which is necessary for creating a framework of best practice. An established framework will help to minimise any potential misuse of these tools, thus reducing the likelihood that welfare could be negatively impacted. As such, the primary aim of this research was to determine how interactive technology is used in zoological institutions across the globe and how they include it in ape exhibitions. The secondary aim was to compare technology-directed behaviours between the four groups of great apes. In the context of this paper, research specifically focused on technology that required engagement from apes, which is referred to as interactive technology throughout the paper.

2. Materials and Methods

2.1. Survey Creation

A 43-question, online survey (S1) in Supplementary Materials was written in English and created using Survey Monkey; it remained live for 102 days. The University of Queensland's Human Ethics Committee (HEA #2018000326) approved this questionnaire. The survey questions were categorised into three sections: (1) participants' attitudes towards providing and using technology in captive great ape management; (2) current practices used by zoos to incorporate technology in ape management and; (3) captive apes' interaction with technology that is currently provided by zoos. For the current paper, we collated and analysed responses to the questions pertaining to current practice, which focused on how zoological institutions use and provide interactive technology (hereafter referred to as technology) for apes. This included information on the provision of technology, length of sessions with technology, the purpose of providing technology to apes, and the different types of technology given to apes. This section of the survey also explored differences in the use of technology between individual apes' sex as well as differences due to group size and genus. Throughout the survey respondents were given questions that were relevant to their reported experience and the survey was programmed to skip sections that were not applicable to the participant based on the information they had provided (S1). There were a variety of question types throughout the survey and most had the option of free text which collected voluntary, additional information from the respondents (S1).

2.2. Participants and Survey Dissemination

The Zoological Information Management Software (ZIMS) Species360, a database of records for ex situ populations of wildlife, was used to generate great ape holding reports across all regions. This provided data on all of the zoological institutions with gorillas, orangutans, chimpanzees, and bonobos in June 2018. From this, the survey was disseminated to 263 institutions via email. The survey was also promoted in zookeeper groups on the Facebook platform. Various zoological associations promoted the survey to maximise the response rate; the World Association of Zoos and Aquariums endorsed and promoted the survey and the British and Irish Association of Zoos and Aquariums promoted it. The participant inclusion criteria were: (1) those that worked at a zoological institution; (2) were the primary caregiver for one of the four ape groups; and (3) agreed with the survey's ethics statements. Respondents were advised to only complete one survey per species per facility and if organisations housed more than one species of ape, a separate survey per species was encouraged. Participants received all necessary information via email and agreed to participate in the survey before answering any questions.

2.3. Data Collection and Analysis

Survey responses were downloaded from Survey Monkey and organised using Microsoft Excel® 2016 (Microsoft Corporation, Professional Plus). Responses were excluded if they did not meet the inclusion criteria (stated in Section 2.2), and as this paper focused on current practices only data pertaining to the current use of technology were used. IBM SPSS Statistics for Windows, version 26.0 (IBM Corp. Armonk, NY, USA) was used to further organise and analyse the data. For the multiple-choice questions, there were many categorical answers with few responses so for the purpose of data analyses the original responses were amalgamated into groups as per Table 1. Responses that could not be grouped and had counts of less than five were only included in the descriptive statistical analyses. Before analysing the data, the "weight cases" function was applied, which accounted for the number of times a variable combination appeared in the dataset. A chi-squared test of independence (χ^2) was used to test for associations between survey questions and ape genus. All data were tested with a 95% confidence interval, and a significant result was determined by $p < 0.05$. To compare the population proportions of ape genera for questions with data from a single categorical variable, a two-tailed z-test (Z) was used. Low sample sizes prevented some ape genera being statistically compared for some survey questions.

Table 1. The original responses to survey questions that were amalgamated for the purpose of data analyses.

Question	Original Response	Amalgamated Response
What is the purpose of using technology with captive great apes?	Medical General husbandry	Husbandry
	Entertainment Education	Public engagement
	Cognitive Language	Research
	Ape to keeper Ape to public Ape to ape	Communication
Choose the 'best fit' to describe your job role/position	Keepers Senior keepers	Keeper
	Volunteers Researchers Directors Veterinarians Enrichment/Training Coordinator Primate Team Leader Programmes Officer	Other
	Multiple species Single species	Manager of a species exhibit
What region are you located?	Canada United States of America	North America
	UK Europe	Europe
	Africa Middle East South America Pacific Russia	Other

NVivo 12 Plus for Windows, version 12.6.0.959 was used to analyse open-ended questions with more than 10 responses. Word clouds displayed the 20 most frequent words, with a minimum length of five letters, and grouped synonyms together. This reduced

the word cloud to only thematic words, which decreased the chance of connecting words (the, and, used, etc.) from appearing. The top five most common key words helped to assess the consensus and general themes of the open-ended comments. "Technology" and "interactive" were excluded from the key words because all open-ended questions were related to this topic. Responses were categorised by sentiment (positive or negative), which provided context and therefore allowed inferences of the respondents' attitude to be made.

3. Results

3.1. Participants

A total of 318 survey responses were received and, of those, participants most commonly cared for chimpanzees (47%). A total of 118 responses were excluded as they did not provide any answers beyond the ape genera. The remaining 200 participants that were used in analyses had responses for more than one question, but some respondents did not answer all questions (Table 2). Over half of the participants were from either Europe (41%) or North America (39%), and those that selected "Other" for their region came from the Middle East (3%), Russia (1%), the Pacific (1%), South America (1%), and Africa (1%) (Table 2). Female participants were more common (66%) than male (33%), and 43% of respondents were between 30 and 40 years old. Zookeepers at a general or senior level made up 41% of participants, and the 16% that selected "Other" as a job position included, but were not limited to, veterinarians, researchers, volunteers, and directors (Table 2). Over half of the participants had been working with captive non-domestic animals for more than 15 years (51%) and it was most common for respondents to be working at a very large facility with over 100 paid employees (47%).

Table 2. Respondent demographics from a 43-question, online survey. "n" indicates the total number of responses per question and "n_i" represents the number of responses for each variable. The number of paid, full-time employees (FTE) represented the size of the facility.

Demographic Variable	Category	n_i	%
Genus of ape (n = 318)	Chimpanzees	148	46.5
	Orangutans	85	26.7
	Gorillas	75	23.6
	Bonobos	10	3.2
Gender (n = 200)	Female	131	65.5
	Male	65	32.5
	Prefer not to say	3	1.5
	Other	1	0.5
Region (n = 200)	Europe	83	41.0
	North America	78	39.0
	Asia	13	6.5
	Australia and New Zealand	13	6.5
	Other	13	7.0
Age (n = 198)	20 to 30	22	11.0
	30 to 40	86	43.0
	40 to 50	60	30.0
	50 to 60	26	13.0
	Prefer not to say	4	2.0
Job position (n = 200)	Keeper	82	41.0
	Curator or facility manager	63	31.5
	Other	31	15.5
	Manager of species exhibit	24	12.0

Table 2. *Cont.*

Demographic Variable	Category	n_i	%
Length of time at facility in current position (n = 200)	Under one year	16	8.0
	One to two years	20	10.0
	Three to five years	44	22.0
	Six to 10 years	56	28.0
	11 to 15 years	24	12.0
	Greater than 15 years	40	20.0
Length of time working with captive, non-domestic animals (n = 200)	Under one year	1	0.5
	One to two years	4	2.0
	Three to five years	18	9.0
	Six to 10 years	36	18.0
	11 to 15 years	39	19.5
	Greater than 15 years	102	51.0
Size of facility (number of FTE employees) (n = 200)	Small—1 to 20	8	4.0
	Medium—21 to 50	40	20.0
	Large—51 to 100	59	29.5
	Very large—100 or greater	93	46.5

3.2. Provision and Use of Technology

From the participants that reported direct ape engagement with technology, the most common type of technology used was portable touchscreen devices (e.g., smart phones and tablets) (60%) (Table 3). This result did not differ between the different ape groups (Table 4). No respondents reported the use of technology like ape-operated cameras or videos, controlled temperature gauges, ape-controlled lights, or ape-controlled music. Several respondents mentioned further types of technology in the comments section, including operant conditioning devices such as machines with lights and levers that when pushed the ape received a reward and similarly, push buttons that provided water or food.

Table 3. Responses from a 43-question, online survey on the provision and use of interactive technology. Within the variable column, the total number of responses provided irrespective of the level is indicated (n), the proportion (%) of responses is provided, and N indicates the total number of responses for each question level.

Variable	Level	N	% [1]
Direct engagement (n = 193)	Yes	49	24.7
	No	149	75.3
Technology type (n = 64)	Portable touchscreen	38	59.4
	Touchscreen computers	15	23.4
	Food vending machines	5	7.8
	Other 'touch' technology	2	3.1
	Joystick interface	2	3.1
	Touchscreen television	1	1.6
	Keyboard interface	1	1.6
Purpose of using interactive technology with captive great apes (n = 85)	Enrichment	45	52.9
	Research	17	20.0
	Communication	9	10.6
	Public Engagement	8	9.4
	Husbandry	6	7.1

Table 3. *Cont.*

Variable	Level	N	% [1]
How regularly are the apes provided with access to the technology (n = 46)	Permanently	1	2.2
	Daily	7	15.2
	Once a week	7	15.2
	Twice a week	6	13.0
	Once a fortnight	6	13.0
	Once a month	9	19.6
	Less often than once a month	4	8.7
	Other	6	13.0
Length of time sessions are offered to apes/minutes (n = 45)	5	5	11.1
	10	11	24.4
	15	7	15.6
	30	6	13.3
	60	1	2.2
	As long as they are interested	13	28.9
	Other	2	4.4
Use of technology during the ape's allotted time (n = 44)	The apes have total freedom to come and go as they wish	39	88.6
	Training session for the allocated time and they must stay the entire time	5	11.4
Provision of technology to apes (n = 41)	Technology is outside the enclosure and keeper is present.	34	82.9
	Technology is outside the enclosure and keeper is not present.	5	12.2
	Technology is temporary in the enclosure with the ape and keeper is present	2	4.9
Interaction with technology between sexes (n = 41)	No—depends on the individual	29	70.7
	Yes—females are more engaged	8	19.5
	Yes—males are more engaged	2	4.9
	No—depends more on age	2	4.9
Group ape interaction with technology (n = 44)	Individually	28	63.6
	Group as they choose	13	29.5
	2 apes at a time	1	2.3
	3 apes at a time	1	2.3
	Other	1	2.3

[1] The levels for each variable total 100%.

Table 4. Output from statistical analyses. The 'n' indicates the total number of responses irrespective of ape group for the respective variable. The 'Y' indicates the ape groups that were compared for the corresponding test statistic.

Variable	Level	Bonobos	Chimpanzees	Gorillas	Orangutans	Test Statistic	*p*-Value
Technology type (n = 32)	Portable touchscreen		Y		Y	Z = 1.48	0.138
Direct engagement (n = 193)	Yes No	Y	Y	Y	Y	X^2 = 4.99	0.082
Provision of technology to apes (n = 30)	Technology is outside the enclosure and keeper is present.		Y		Y	Z = −1.11	0.267
Use of technology during the ape's allotted time (n = 33)	The apes have total freedom to come and go as they wish		Y		Y	Z = 1.91	0.053
Purpose of using interactive technology with captive great apes (n = 37)	Enrichment		Y		Y	Z = −1.11	0.267
Interaction with technology between sexes	No—depends on the individual (n = 18)			Y	Y	Z = 1.633	0.103
	No—depends on the individual (n = 15)		Y	Y		Z = −1.833	0.672
	No—depends on the individual (n = 21)		Y		Y	Z = 0.396	0.689
Group ape interaction with technology (n = 35)	Individually Group		Y		Y	X^2 = 0.062	0.546

3.2.1. Direct Engagement

It was more common for respondents to have apes not directly engaged with technology (75%) than directly engaged with technology (Table 3). Although respondents were ineligible to complete the remainder of the survey, the option to provide further explanation was available for those whose apes did not engage directly with technology. Reasons for no direct engagement between apes and technology included apes that were uninterested in the technology, there was a lack of zookeeper knowledge about the technology, no technology was used at all, or there were concerns that technology use would impact welfare of the apes. This feedback was supported by the word cloud key words. The five most common keywords used by respondents whose apes did not engage with technology were enrichment, natural, animals, behaviours, and social. These were generally used in a negative context, for example, "I disagree in the principle of giving them technology as just toys (e.g., playing piano on a tablet), as it does not promote natural behaviours and hinders social interactions."

3.2.2. Provision of Technology to Apes

Ape–technology interactions were most commonly provided in a restricted manner by zookeepers; 83% of ape–technology interactions were provided from the outside of the enclosure, with the keeper present and apes accessing the technology with their fingers, toes, or tools. When participants were asked about the regularity of technology provision, only 1 out of 46 respondents provided their apes with permanent access to technology and the remainder temporally restricted access (Table 3). Some respondents offered interactive technology to their apes for as long as they were interested (29%). However, the remaining respondents provided time limits per session, the most common of which was 10 min (24%) (Table 3).

3.2.3. Use of Technology during Allotted Time

Evidence from the additional comments suggested that the regularity with which apes were provided with interactive technology was often at the keeper's discretion and influenced by time availability and knowledge of the technology. Other comments included that technology provision was random or irregular, depended on the purpose for providing technology, and up to the discretion of the caregiver. This feedback supported findings from the word cloud. The five most common keywords used by respondents were discretion, keeper, control, schedule, and research. Participants commonly reported that they provided their apes with the freedom to use technology during the scheduled time zoos had allocated for providing apes with technology (89%), allowing the apes to engage as they wished. This result did not differ between the ape groups (Table 4). Further comments suggested that providing freedom of use encourages apes to use it and gives them choice.

3.2.4. Purpose of Providing Technology in Zoos

Enrichment was the most common reason (53%) for providing captive apes with technology and this did not differ between ape groups (Table 4). Research was the second most common reason (20%), followed by communication (11%), and the remaining reasons (i.e., public engagement and husbandry) made up less than 10% of responses.

3.3. Ape Interactions with Technology

Participants commonly reported that engagement with technology depended on the individual animal (69%). However, this did not differ between ape groups (Table 4). For example, one respondent reported that "an older male showed little interest in the applications until he was shown the mirror [app]. He seemed to enjoy looking at his face, nostrils, and open mouth." Respondents stated that individuals most commonly (64%) interacted with technology by themselves. However, group use of technology was also reported (Tables 3 and 4). Additional comments from the open-ended, free-text question suggested that most captive apes were given their own device, but where infant apes were present, they watched their mother interact with technology while on their mother's back. Additionally, one participant reported, "one monopolises the time, so [I] have to try to separate [them] or others try to participate."

4. Discussion

4.1. Purpose of Using Technology in Zoos

Technology provides cognitive challenges and an element of choice for captive apes, both of which are important for supporting ape welfare [5,28]. Our results show that, regardless of ape genus, enrichment was the most common reason for providing apes with technology. The benefits of digital enrichment include its flexibility, adaptability, and ability to provide animals with a wide range of activities of varying levels of complexity, which allows it to be individually customizable and potentially resistant to habituation on repeated exposure [5,29–31]. Another benefit of using technology as a source of environmental enrichment is its ability to provide apes with some control over their environment [28], which is thought to improve mental well-being [5]. Environmental control may be exhibited through actions such as operating a remote feeder, choosing social interactions or play activities, or deciding the temperature, lighting, or music played in the enclosure. Additionally, through active participation, technology can benefit ape physical welfare [5]. For example, the Indianapolis Zoo Orangutan Center has incorporated inbuilt remote feeders into the outdoor yard, which individuals can press to release food when buttons are illuminated [32]. This technology provides the orangutans with a food choice and by placing the remote feeders out in the yard, activity is encouraged [32]. Future research should assess the benefits and impacts of using technology as enrichment for apes.

An emerging field in captive management is the use of technology, such as microchip-automated devices, to improve and individualise husbandry practices by controlling nest box doors [24], access to food [22], and access to specific sections of enclosures [23]. However, only a small proportion of respondents used technology for husbandry purposes in this study, possibly due to a lack of awareness and knowledge amongst zoological institutions about technology (e.g., microchip-automated devices and GPS collars) that is not as commonly used in everyday human life as portable technology is. Additionally, cost may prevent the use of such technology, and therefore cost-effective solutions are more important now than ever before due to the economic impacts from the COVID-19 pandemic [23]. Although such devices are now commercially available, the price remains high for a sector with low profitability.

Another consideration for a low number of responses for this category is the ethical implications of using such technology. Currently, there are no internationally defined limits on the acceptable use of implantable microchips to prevent the harmful use of this technology. Invasive technology such as microchips, may require surgery, increased self-inflicted trauma due to the surgical wound, and an increased chance of disease development around the site of implantation [33]. The likeness between humans and apes makes the lack of rules surrounding this technology concerning as it could raise social, political, and philosophical issues; consequently, determining these regulations should be a high priority.

The expanded use of technology within zoo exhibits is likely to be influenced by staff familiarity and proficiency with technological options. Professional development within zoological institutions comes from workshops, certifications, and conferences. If these technologies have yet to reach these events, they are unlikely to be incorporated into everyday husbandry routines. The expense and limited research into their benefits, and absence of widely accessible knowledge about these devices, may position these technologies as a luxury item and unnecessary for the improvement of ape husbandry. To date no cost–benefit analysis has been conducted for any type of technology, despite previous publications highlighting the need for such analyses [5]; our research also advocates for such an investigation as it will be essential to the future success of implementing technology in zoos. An alternative solution to avoid the expense of technology is to use donated items from the public. For example, zoos could use social media to request public donations of tablets that could be used provided they were made safe for the apes. Additionally, improving the communication between research and zoological institutions in the use of technology by humans for ape husbandry processes could contribute to an increase in technology use. It would also be important to consider evaluating how the purpose (e.g., research, enrichment, or husbandry) of integrating technology influences its use and impacts ape welfare.

4.2. Types of Technology Used at Zoos

Our findings show that portable devices (e.g., tablets and smart phones) are the most popular type of technology provided by zoos to apes across all genera, possibility attributable to the fact that the most common purpose of providing technology to great apes was for enrichment. The open-ended responses from our survey demonstrated that portable technology is versatile; respondents indicated that they provided their apes with a range of activities (e.g., applications to watch videos, play games, and use the selfie camera), which is a simple way of increasing choice and cognitive stimulation. In comparison to other technology types (e.g., temperature gauges, light switches, joysticks, and food vending machines), portable devices are commercially available and affordable. Nowadays, one could assume most people have everyday access to similar portable technology that is being used with apes and consequently knowledge on how to use them. This pre-existing knowledge will result in less training required by the zookeepers to implement technology with their apes, which will also save zoos money compared to incorporating more complex technologies (e.g., computer-controlled puzzles or ape-controlled technology).

Many respondents did not use options such as food vending machines, light switches, and temperature gauges. Reasons for this were not specified but could plausibly be because of their limited functionality; they cannot always be adapted to the individual ape, may require installation, and are often permanent fixtures in enclosures. However, there is existing evidence that this technology is being used by zoos [4]. For example, the Indianapolis Zoo Simon Skjodt International Orangutan Center provides apes with touch-panel vending machines [32] and Zoo Atlanta has inbuilt touchscreen computers inside an artificial trees for orangutans [30]. Cost–benefit analyses of the various technology types, determining appropriate criteria to assess the success and failure of introducing technology into captive ape management and assessing the welfare benefits and implications of such technology would build upon this study's findings. It would provide essential information to zoos and allow institutions to make informed decisions about which technology is most practical for their circumstances.

4.3. Technology and Ape Welfare

4.3.1. Natural Behaviours

Behaviour is often classified into natural or unnatural, but the appropriateness of this categorisation is a heavily debated topic amongst animal welfare scientists [34,35]. It is necessary to discuss the various viewpoints as it provides a possible reason for the reported use of technology in zoos. A common goal for zoological institutions globally is to maintain a high standard of welfare [36] and the success of this can be influenced by the provision and type of enrichment [27]. This survey found that most participants did not have apes directly engaging with technology, which may be attributed to the common perspective that natural behaviours are conducive to higher levels of animal welfare compared to unnatural behaviours [34,35]. It was clear that this viewpoint also influenced our findings because some participants provided extra comments that, in summary, expressed their belief that technology was unnatural; responses included technology would not enhance mental welfare and there are other natural and challenging activities available, technology is not a necessity, and it is not a natural behaviour. Despite this perception, there are benefits of technology on ape welfare, for example, it can provide apes with a wide range of activities with varying levels of complexity, which allows it to be individually customizable and has the potential to be resistant to habituation on repeated exposure [5,29–31]. Apes are able to engage directly and indirectly with technology [27,37,38] and therefore may provide a long-term solution to the need for cognitive stimulation [5], which would see an improvement in mental welfare. Additionally, through active participation, technology could benefit ape physical health [5].

A finite distinction between natural and unnatural behaviours is elusive as some enrichment activities may utilise wild-type behaviours in conjunction with artificial objects. For example, previous research used remote feeders that were made from wooden structures and technology, which encouraged dexterity and activity in orangutans [32]. The provision of technology in this manner has been termed "functionally naturalistic", which ensures that similar brain structures, movements, or behaviours mimic those of wild-born individuals [32]. Additionally, "functionally naturalistic" ape–technology interactions could address concerns about the naturalness of providing apes with relative cognitively complex tasks, such as solving a computer puzzle, interacting on video calls, or painting on a tablet. This method of provision would help create a "functionally appropriate non-human primate environment", which does not involve mimicking their wild habitats, but identifies elements of ape environments that encourages species-typical behaviours [39]. For example, similar brain structures are used when apes complete touch-panel, problem-solving tasks as when they are planning, navigating, and foraging in forest habitats [32]. It is also possible to adapt the location and timing of ape–technology interactions to mimic wild-type feeding patterns [32].

Results from the current study do not directly determine whether technology was provided in a "functionally naturalistic manner", but they do show that technology was provided predominantly from the outside of the enclosure, and there was no difference in the methods of provision between the ape genera. The prevalence of this approach brings into question how long apes' access to technology will be restricted. It is possible that not providing technology appropriately to apes could increase frustration, inter-group competition or cause concern in visitors that are observing the ape–technology interaction. Future research should be in collaboration with zoos to optimise the provision of technology in a cost-effective and ape-friendly manner. To do this, research must first identify the zoo's goal of providing enrichment, assess the success and failure of incorporating technology, and then measure the impact on animal welfare.

Comparisons between zoo-based and wild activity budgets are a common way to measure captive animal welfare [34,35,40], with differences from their wild counterparts assumed to represent a decrease in welfare in zoo-housed animals [35]. Therefore, to minimise a reduction in natural behaviours and avoid this perceived impact on welfare, enrichment often focuses on increasing wild-type behaviours regardless of the benefits or drawbacks these have to the animal's current environment [35]. Not all wild-type behaviours are beneficial to a captive context, nor are they all conducive to an increase in welfare. For example, predator avoidance and resource limitations are natural experiences in the wild, but also cause anxiety, fear, and hypervigilance, which are states associated with a decrease in welfare [41]. The stance zoos have towards the natural behaviour debate may also be influenced by the underlying motivations for housing animals in zoos. For example, zoos that contribute to captive breeding and reintroduction programmes have primary goals of minimising human interaction and encouraging wild-type behaviours, such as foraging, predator avoidance, and grooming, because they are expected to increase post-release survival [42]. However, zoo-based captive breeding for release programmes are not common practice for primates because of their complex social structure and behavioural repertoire [43], and past attempts have been a mixture of successes and failures [42–45]. Consequently, zoos are not the main contributor to ape reintroduction programmes [46], hence it may be unnecessary for zoos to focus on replicating wild-type behaviours in apes as they are not being released. Our study found no association between ape genus in the reported direct engagement with technology.

4.3.2. Individual Differences in Apes and Technology Use

Ape personality has been described as "human-like" and is generally measured using a comprehensive list of behavioural traits [47]. There is already evidence that individual differences between apes gives rise to different technology preferences [48,49] and our survey results support this as most respondents reported individual differences in ape–technology interactions rather than age- or sex-based differences. However, in a social animal it is difficult to disentangle the behaviour of an individual from group dynamics, and therefore future research needs to investigate whether individual differences influence technology use or whether group dynamics (e.g., dominance relationships) determine access to a resource. The variation in individual ape–technology interactions indicate that to promote welfare a simple implementation process for technology is not possible, and consideration of individual variation and preferences is needed to integrate technology in captive programmes. While research in this field is sparse, it may be beneficial to draw upon research on human–technology interactions to avoid the possible negative effects of technology interactions. Until further research is conducted into the relationship between ape personality and technology preference, similarities between humans and apes gained from existing personality research [50] may provide an indication of how to implement technology into captive ape management.

4.3.3. Ape Access to Technology

The approach for the provision of technology needs to be carefully considered as it is likely to influence ape welfare. The current study found that most apes in the participating zoos had restricted interactions with technology; zookeepers controlled the time, remained present during ape–technology interactions, and restricted physical access to the technology. However, the most common type of session apes received was flexible, giving the apes freedom to come and go as they wish during the sessions, irrespective of genus. In the open-ended questions zookeepers made it clear that access was restricted because of resource limitations (e.g., keeper availability, number of tablets, and time restrictions). Previous research indicates that orangutans demonstrate undesirable behavioural changes, such as increased aggression amongst the group, anxiety, and reduced feeding when provided with computers [31]. Screen time is known to negatively influence cognitive development, sleep, and activity levels in children [51], and so current recommendations are that children aged two to five should have a maximum of one hour of screen time per day [52]. Similarities in the effects that technology has on apes and children are likely because of the similarity in brain structure between apes and human toddlers [12]. This may allow us to draw a parallel and estimate how apes could react to prolonged exposure to technology in the absence of existing information on ape–technology interactions.

Our results also reported that apes predominantly interact with technology alone rather than with conspecifics regardless of genus, and likewise research suggests that human children have a preference for interacting with technology alone [53]. These similarities between apes and children further support the suggestion to draw upon paediatric research to inform decisions about ape–technology interactions. However, to create accurate guidelines for ape–technology interactions it would be beneficial to conduct longitudinal studies to investigate the relationship between exposure to technology and ape brain development, function, and behaviour. Provision and exposure to technology should be monitored until research has assessed the impacts on welfare and guidelines can be created.

4.4. Limitations

This study obtained data from many zoological institutions, spanning a wide range of regions across the globe. However, one potential limitation of this study is that participants from North America and Europe were over-represented and that may reflect the Western, educated, industrialized, rich, and democratic countries (WEIRD). Technology is widely available in these areas, compared to some of the regions that do not meet these demographics. This includes access to information on the advances and applications of technology as digital enrichment and affordability of devices. The lower number of responses from regions where English is not the first language may be explained by having only disseminated the survey in written English. Future research should create a survey with a primary goal of gathering in-formation from countries that do not meet the WEIRD criteria. This would allow appropriate representation across regions that vary in aspects such as language, culture, animal–human relationships, and socioeconomics.

Although this study included over 200 zoological institutions, there were differences between the number of respondents caring for different ape genera. This was partially driven by differences in holdings across zoos. Lastly, it was unclear which respondents had completed the survey multiple times for different species as not all respondents indicated the specific zoo that they were employed in. While this did not affect species specific information, it may have resulted in some duplication of demographic data. This could have been avoided by asking whether the respondent had completed this survey for another ape genus.

A final potential limitation was the lack of distinction between "no engagement, but apes were provided with access to technology and did not interact" and "no engagement because the zoos did not have the technology." Although some participants explained their answer in the optional open-ended comments, it was not clear for all respondents why they had selected a particular answer. Consequently, respondents that provide technology to their apes, but indicated that there was no engagement, were not able to complete the remainder of the survey as it automatically took them to the end. This exclusion of respondents has limited us to information from zoological institutions that have successful direct engagement.

5. Conclusions

It is clear there is no current standardised method to incorporate technology into captive great ape management. At present, many zoos appear to use technology for enrichment purposes when time, personnel, and finances permit. The lack of known methods of best practice leads us to suggest that future research must investigate the success and failure of ape–technology interactions and its impact on welfare. There are similarities between a human child and an ape brain, and technology is known to negatively affect the development of a child's brain, which makes the lack of existing information on ape–technology interactions concerning. Consequently, not only is research necessary to address these concerns, but effective communication and transparency of results between scientists and zoological institutions are imperative to developing and providing technology that meet the goals of the AZA and zoological organisations globally. If methods of best practice are identified, innovative methods of using technology in zoos can be explored.

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