Genetics & Biodiversity Journal

Journal homepage: https://journals.univ tlemcen.dz/GABJ/index.php/GABJ

ISSN: 2588-185X

OPEN ACCESS

Short communication

The impact of zoo visitors on the behaviour of black lemurs (*Eulemur macaco*) and ring-tailed lemurs (*Lemur catta*) assessed with artificial intelligence

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***Article history:* :** Received: April 21, 2024, revised: May 4, 2024, Accepted: July 9, 2024

Abstract

Machine learning techniques have been used for observing zoo animals and quantifying their behaviour. This study investigates the behaviour of black lemurs *(Eulemur macaco)* and ring-tailed lemurs (*Lemur catta*) in a new walk-through enclosure at Aalborg Zoo in Denmark, on a day with many visitors (1,031 visitors) and on a day with few visitors (181) for observing possible differences in four types of lemur behaviors: 'locomotion', 'resting', 'eating', and 'grooming'. By using both manually observed data and machine learning, this study compares the methods and explores the lemurs´ behaviours. The Wilcoxon rank sum tests of the four behaviours manually estimated in the two days for ring-tailed lemurs showed that the visitors were significantly affecting several of these behaviours. However, locomotor activity was not found to be significantly different in the two days for black lemurs, but when testing the data obtained with the machine learning approach, a significant difference between days was found. The results suggest that the manual approach can complement a machine learning approach in behavioural studies.

Keywords: Aalborg Zoo, animal welfare, Create ML, Machine Learning (ML) techniques, RectLabel Pro

ملخص

تم استخدام تقنيات التعلم الآلي لمراقبة حيوانات الحديقة وقياس سلوكها. يهدف هذا البحث إلى دراسة سلوك الليمورات السوداء (Eulemur macaco) والليمورات ذات الذيل الخاتم (Lemur catta) في مساحة جديدة في حديقة الحيوانات في آلبورج في الدنمارك، في يوم زيارة للحديقة بعدد كبير من الزوار (1،031 زائرًا) وفي يوم زيارة بعدد قليل من الزوار (181 زائرًا) لمراقبة الاختلافات المحتملة في أربعة أنواع من سلوك الليمورات: 'الحركة'، 'الراحة'، 'التغذية'، و 'التنظيف'. من خلال استخدام بيانات الملاحظة اليدوية وتقنيات التعلم الآلي، يقارن هذا البحث بين الأساليب ويستكشف سلوك الليمورات. أظهرت اختبارات فحص الترتيب بويلكوكسون للسلوك اليدوي لليمورات ذات الذيل الخاتم في اليومين أن الزوار يؤثرون بشكل ملحوظ على السلوك في العديد من هذه الأنواع. ومع ذلك، لم يتم العثور على فرق ملحوظ في النشاط المحرك في اليومين لليمورات السوداء، ولكن عند اختبار البيانات المحصلة بالطريقة التي تعتمد على التعلم الآلي، تم العثور على فرق ملحوظ بين الأيام. تشير النتائج إلى أن الطريقة اليدوية يمكن أن تكمل الطريقة التي تعتمد على التعلم الآلي في الدراسات السلوكية.

الكلمات الرئيسية:

حديقة الحيوانات في آلبورج، رفاهية الحيوانات، إنشاء RectLabel Pro ، تقنيات التعلم الآلي، برنامجML

Introduction

In many zoos, the visitors can both watch and interact with the animals (Ross *et al.*, 2012). In these cases, it is important to ensure that visitors do not negatively impact captive animals, both for reasons of animal welfare and ethical considerations as well as the risk of giving the visitors a negative experience (Sherwen & Hemsworth, 2019). Visitors' effect on captive animals is often unpredictable and may have varying impacts on the animals, depending on the species, the enclosures and how the visitors act around them (Sherwen & Hemsworth, 2019). Research has shown that visitors can also influence captive animals positively (Ross *et al.*, 2012). Visitors can contribute as an enrichment factor, which is shown to decrease stereotypical behaviour (Sharma *et al.*, 2023). Attention seeking, playfulness and non-hiding behaviour can all be positive effects of zoo visitors in the zoo (Sherwen & Hemsworth, 2019). Therefore, the access of visitors is often used as an enrichment in new enclosures (Sharma *et al.*, 2023).

Williams and Coworkers (2021) studied the behaviour of African penguins and meerkats in four different zoos during the COVID-19 shutdown, as well as the first few months after the zoos were reopened for visitors. Generally, the meerkats showed more positive behaviour when the zoos were open for visitors, while the African penguins did not show any change in behaviour during the shutdown and the reopening (Williams *et al.*, 2021). A study by Sherwen and Coworkers (2015) of two kangaroo species living in a walk-through enclosure has shown that the kangaroos' behaviour only changed slightly on busy days compared to quiet days. On busy days, the kangaroos were more attentive to the visitors, and one of the species had slightly more locomotion and tended to use more of the enclosure area. There was no evidence that kangaroos living in a walk-through enclosure had any negative welfare effects on busy days (Sherwen *et al.*, 2015). Enrichment of visitor-interactions has also been documented in primates (Sharma *et al.*, 2023). Their study performed at Kathmandu in Nepal, showed that rhesus macaques had reduced abnormal and stress-related behaviour, when visitors were present (Sharma *et al.*, 2023). Lewis and Coworkers (2020) investigated the behaviour of western lowland gorillas in London Zoo in England. They found that the gorillas had increased locomotion and decreased environmentally related behaviours when exposed to visitor crowds (Lewis *et al.*, 2020). It is therefore clear that species-specific differences in how animals react to visitor-interactions exist (Hosey *et al.*, 2023). It could be speculated that large primates, such as great apes, would see visitors as less of a threat because of their own size, and therefore not be negatively affected compared to smaller primates (Hosey *et al.*, 2023). However, great apes might also see visitors as more of a threat because they share many behavioural signals with humans (Hosey *et al.*, 2023). For studying visitors' impact on animal welfare, the most common method is to monitor aggression, avoidance and stereotypies indicating bad welfare, whereas exploratory, playful, and affiliative behaviours may indicate positive welfare states. Species can react differently, and such parameters can therefore never stand alone (Sherwen & Hemsworth, 2019). Stereotypical behaviour is repetitive abnormal behaviours, often in primates shown by self-scratching, rocking, clapping and sticking out their tongue (Kummrow, 2020). Zoo visitors who observe these stereotypic behaviours in animals are more likely to perceive that the general welfare in the zoo is poor (Sherwen & Hemsworth, 2019). A study by Learmonth and Coworkers (2021) showed that visitors rated lower welfare for pacing tigers than for inactive tigers. Information and dialog seem to be key factors for how the visitors perceive the animals. A study by Warsaw & Sayers (2020) showed that the visitors in Wellington Zoo in New Zealand had a negative attitude towards the welfare of a spider monkey, who was limping. After being informed that the spider monkey had just returned from the veterinarian being treated and was recovering well, their attitude towards the welfare became more positive. Organizations such as Danish Association of Zoos and Aquaria (DAZA), European Association of Zoos and Aquaria (EAZA) and World Association of Zoos and Aquaria (WAZA) focus on improving animal welfare and nature conservation, as well as performing research in zoos and contribute to mediation of knowledge to the visitors (Hvilsom *et al.*, 2020). In recent years zoos that are members of these organizations have focused more on conservation, scientific research and animal welfare. In 2023 Aalborg Zoo opened a new enclosure (*Madagascar)*, where black lemurs (*Eulemur macaco*) and ring-tailed lemurs (*Lemur catta*) reside, so it was possible for visitors to walk through the enclosure. Although many studies have been performed on the behaviour of lemur species, there is still only little research into their interactions with the enclosures. In this study, the behaviour of black and ring-tailed lemurs and their possible behavioural changes during visitor-interaction were examined using manually collected data and data observed by machine learning. It was also investigated whether machine learning was a useful tool in behavioural research in lemurs. Artificial intelligence (AI) is becoming a useful tool for improving video and image analysis. Machine learning (image analysis are image classification and object detection) allows an automatic identification of individuals or behaviours (Zhou 2016, Zhao *et al.,* 2019). Image classification may identify which individual is shown in a frame, whereas object detection can be used to identifying and labeling behaviors (giving at the same time information about the spatial coordinates and time) (Zuerl *et al.,* 2022).

Materials and Methods

Subjects

The research comprised six ring-tailed lemurs (*Lemur catta*), one male and five female, along with two male black lemurs (*Eulemur macaco*) housed at Aalborg Zoo in Denmark. The two black lemurs came from another European Zoo a few months before the study, and the six ring-tailed lemurs were transferred from an old enclosure in Aalborg Zoo to the new enclosure.

Enclosure

The outdoor walk-through enclosure for the lemurs measured 585 square meters in total, while the indoor enclosure measured 105 square meters. Both species spent the evenings and nights in the indoor enclosure but were let out into the outdoor enclosure in the morning. The visitors could observe the lemurs from the outside through the surrounding fence consisting of net and glass panels. The visitors were allowed to walk through the enclosure on a path between 11 AM and 3 PM. The walk-through enclosure contained different objects for enrichment, including trees for climbing.

Figure 1. Overview of the entire lemur enclosure. The two red dots (1 and 2) show the placement of the cameras. The engraved area illustrates the area used for image recognition in RectLabel Pro.

Data Collection

The data collection took place on two separate days. The first day was October 19th, 2023 - the day with many visitors (1,031 visitors walked through the enclosure). The second day was October 24th, 2023, which was the day with fewer visitors (181 visitors walking through the enclosure) (see also Appendix 1). Two cameras with different angles (Figure 1) were placed in the enclosure and filmed four hours each day from 11 AM to 3 PM. The data was collected and elaborated manually and with the programs RectLabel Pro (Kawamura, 2017; https://rectlabel.com/), Xcode (Apple Developer, 2023) and Create ML (Apple Developer; https://developer.apple.com/documentation/createml). For the manual data analysis, Excel was used to manually note four different behaviours: ‘locomotion’, ‘resting’, ‘eating’ and ‘grooming’ per 30 seconds along with the number of visitors in the walk-through enclosure. These four behaviours were chosen, because they were the most prominent behaviours in the collected video material. Afterwards, for the manual data analysis, an average for each of the behaviours for both species was calculated for every 30 seconds (the number of times that a behaviour was observed in an interval of 30 seconds). For the data collection using machine learning only the locomotion of the lemurs was analysed. The average distance travelled in an interval of 30 seconds was obtained by estimating the total distance travelled by all the individuals, dividing by the number of individuals.

Data Analysis

Manual observations

Descriptive statistic

The program R-studio (https://posit.co/) was used to make boxplots for four selected behaviours on the two days for each species. Furthermore, cumulative curve graphs for locomotion were made for both species. The median, mean, standard deviation, were calculated. A Shapiro-Wilk test was applied for testing deviations from normal distribution of data.

Non-parametric comparison

As the data was not normally distributed, the Wilcoxon rank-sum test was used to compare the median of the distributions of the behavioral data for both species on both days.

Machine Learning

Image recognition analysis

For image recognition RectLabel Pro version 2023.10.22 (2023.10.22) and the developer tool Create ML version 5.0 (121.1) (Apple Developer) from Xcode version 15.0 (15A240d) were used.

To train the image recognition model in Create ML (Apple Developer) annotating the two species in RectLabel was necessary. Since the lemurs are small animals compared to the surroundings, the model needed many annotated images to get a high validation percentage. Using “create polygon using SAM” (Figure 2) 471 ring-tailed lemurs and 315 black lemurs were manually labeled.

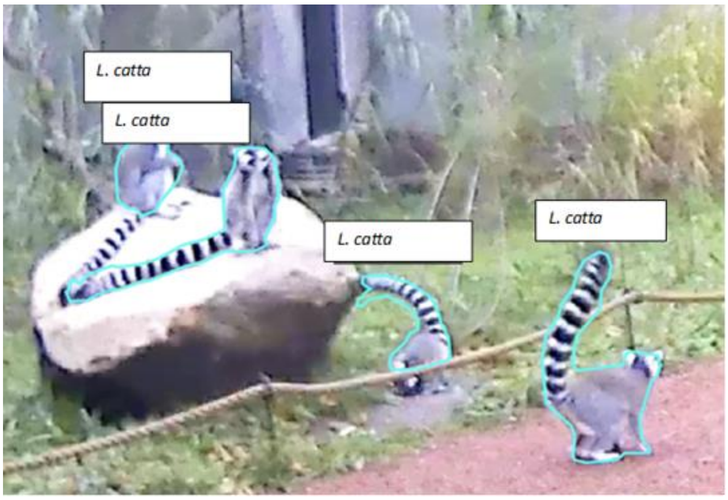

Figure 2. Example of labeling with polygon using SAM in RectLabel Pro on four ring-tailed lemurs (L. catta) in the outdoor walk-through enclosure.

The object detection model in Create ML (Apple Developer) was trained with 3,000 iterations from the training images and the JSON-file. The final trained model gave a 91% test accuracy (see Figure 3 for details of the pipeline).

The 8-hour video material was divided into approximately 15 minute videos using iMovie version 10.3.10. (Apple inc.). The trees and bushes from the enclosure had to be cropped away to keep minimal disturbance, as the model otherwise had trouble telling the difference between ring-taled lemurs and the surrounding bushes. Therefore, only a minor area (Figure 1 and 3) was used for image recognition. Only the video material of camera two was used for image recognition as this camera gave the best angle of the wanted area (Figure 1).

DOI: *10.46325/gabj.v8i2.392*

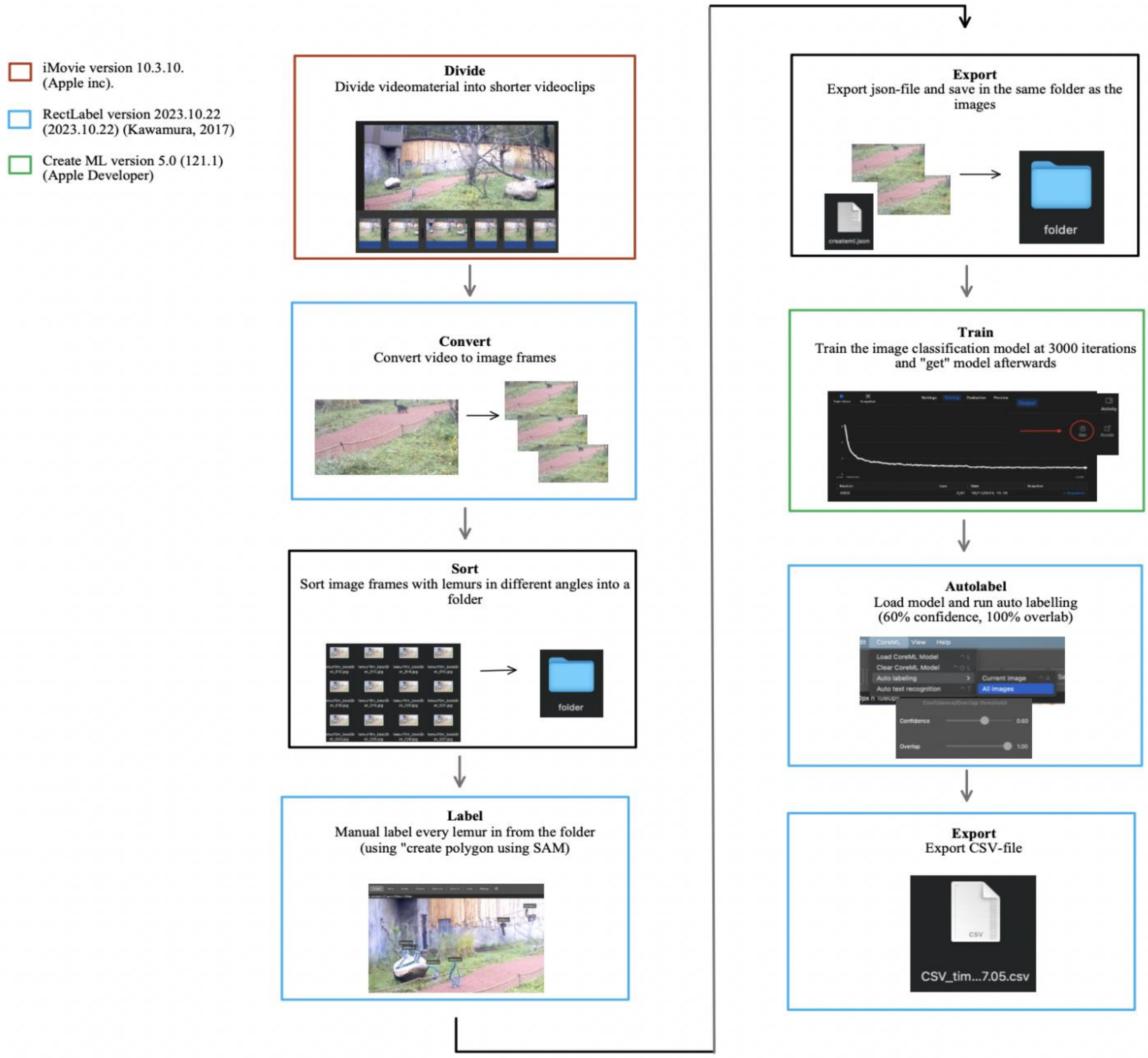

Figure 3. Pipeline for the machine learning-method

Figure 4. Example of a cropped image from camera two used in RectLabel Pro (Kawamura, 2017) illustrating a ring-tailed lemur (L. catta) in the walk-through enclosure. The blue box identified the animal to be a ring-tailed lemur with 91 % certainty and shows its coordinates.

In RectLabel Pro the 15 minutes videos were converted into image frames (30 frames per second (FPS)). The trained image recognition model was loaded in RectLabel Pro (Kawamura, 2017), put on a 60 % confidence (threshold level for accepting a label), 100 % overlap, and used to auto-label the eight-hours of video material. After each 15 minute video was auto-labeled, and a CSV-file was exported into Excel.

Statistics

The CSV-file consists of coordinates from each labeled lemur. To convert the coordinates to a measure of distance, the Euclidean distance formula was used:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Since the image recognition model did not recognize the difference between the six ring-tailed lemurs it caused a problem during data processing, since it was impossible to recognize which coordinates came from which individual. To prevent this source of error, the higher outliers were detected and deleted from the data. The outliers were determined using the formula for calculating the higher outlier:

$$Higher\ outlier = Q3 + (1.5 * IQR),$$

where Q3 is the third quartile and IQR is the interquartile range.

Cumulative graphs, boxplots and the Wilcoxon rank sum tests of locomotion activity were made from the data without outliers and from each day with each lemur species (Legendre & Legendre, 1998).

Results

<u>*Manual observations*</u>

Descriptive statistics

Figure 4 shows boxplots for both species on the two days for each of the four behaviour types. The figure indicates strong deviations from symmetrical distributions and heterogeneity of the variances.

Deviations from normal distributions were confirmed by Shapiro-Wilk tests which showed highly significant p-values (Table 1). The skewness and kurtosis values indicate that the distributions of the averages for each of the behaviour for both species on both days with few and many visitors are not normally distributed due to positive skewness and leptokurtic distributions.

Table 1. Median, mean, standard deviation, skewness, kurtosis, and p-value for the Shapiro-Wilk test for the four different behaviours for ring-tailed lemurs (L. catta) and black lemurs (E. macaco) on the day with many (1,031) and few (181) visitors. NA: none-available.

L. catta (many visitors)						
	Median	Mean	Standard deviation	Skewness	Kurtosis	Shapiro Wilk Test P-value
Locomotion	0.00	0.39	0.55	1.62	5.86	$2.20*10^{-16}$
Resting	0.17	0.49	0.54	0.98	3.42	$2.20*10^{-16}$
Eating	0.00	0.03	0.16	5.07	28.11	$2.20*10^{-16}$
Grooming	0.00	0.00	0.03	9.20	96.23	$2.20*10^{-16}$
L. catta (few visitors)						
Locomotion	0.00	0.33	0.50	3.80	36.63	$2.20*10^{-16}$
Resting	1.00	0.67	0.45	-0.47	1.88	$2.20*10^{-16}$
Eating	0.00	0.16	0.35	1.76	4.26	$2.20*10^{-16}$
Grooming	0.00	0.07	0.23	3.23	12.08	$2.20*10^{-16}$
E. macaco (many visitors)						
Locomotion	1.00	1.35	0.77	0.84	3.07	$1.54*10^{-14}$
Resting	0.50	0.89	0.86	0.86	2.90	$2.13*10^{-15}$
Eating	0.00	0.02	0.14	7.67	66.21	$2.20*10^{-16}$
Grooming	0.000	0.00	0.00	NA	NA	NA
E. macaco (few visitors)						
Locomotion	1.00	0.70	0.41	-0.65	2.31	$2.200*10^{-16}$
Resting	0.50	0.38	0.46	0.79	2.53	$2.200*10^{-16}$
Eating	0.00	0.16	0.24	1.86	4.74	$2.200*10^{-16}$
Grooming	0.00	0.04	0.19	4.46	21.70	$2.200*10^{-16}$

DOI: *10.46325/gabj.v8i2.392*

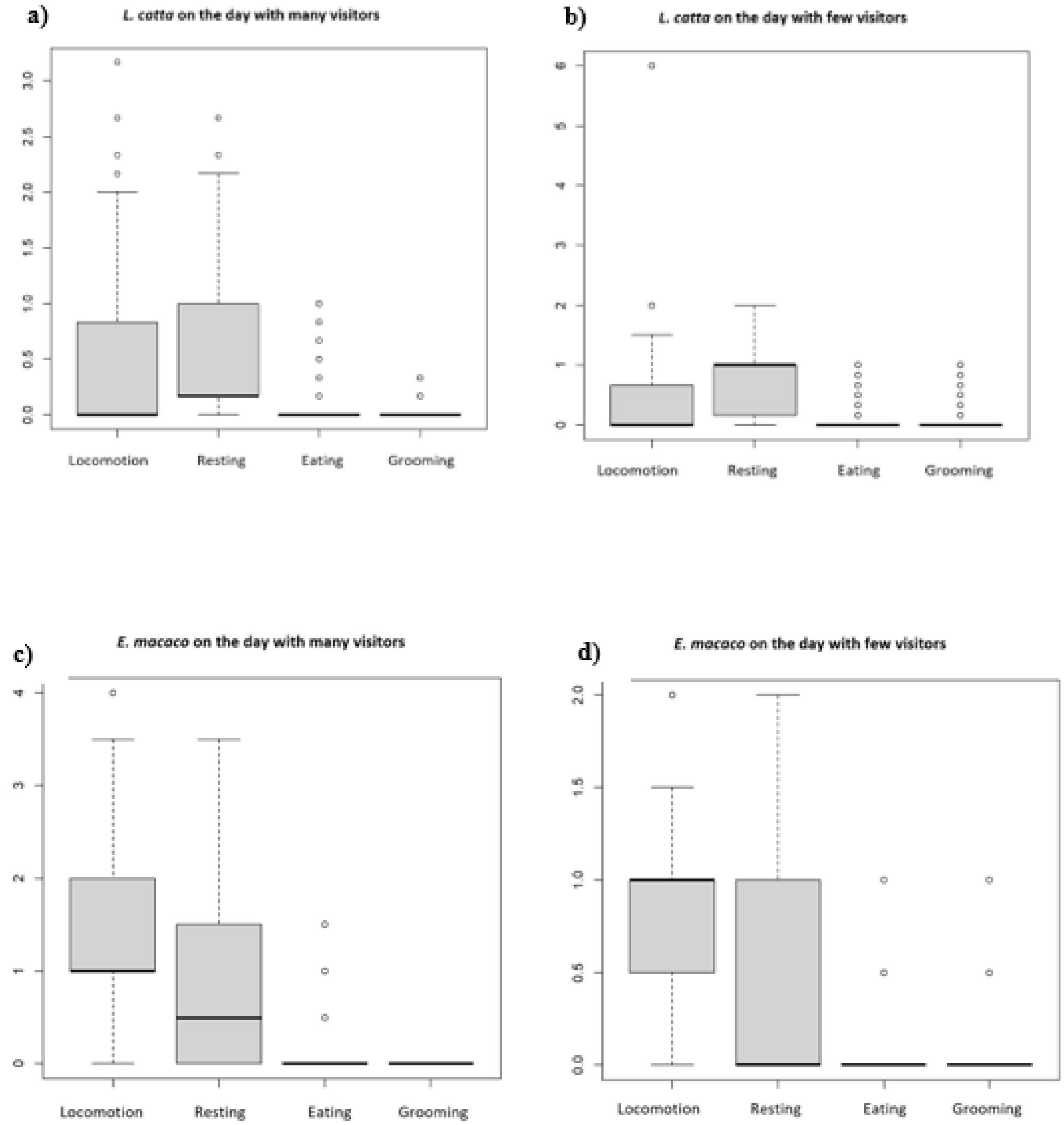

Figure 5 Boxplot of the averages for each behavior; the number of times that a behaviour was observed in an interval of 30 seconds, divided with the number of individuals. For ring-tailed lemurs (L. catta) on the day with many visitors (a), and on the day with few visitors (b), and for black lemurs (E. macaco) on the day with many visitors (c), and on the day with few visitors (d).

Non-parametric comparisons

The Wilcoxon rank sum tests of the four behaviours (Locomotion, Resting, Eating and Grooming) estimated in the two days for ring-tailed lemurs indicated that in the day with many visitors the locomotion activity was significantly higher compared to the day with few visitors. Whereas three of the behaviours (Resting, Eating and Grooming) were significantly higher in the day with few visitors (Table 2). The black lemurs did not show significant differences for the locomotion activity during the two days and showed significantly higher resting behaviour in the day with many visitors compared to the day with few visitors, whereas two behaviours (Eating and Grooming) were significantly lower at the day with many visitors compared to the day with few visitors (Table 2).

Table 2. Medians of the number of times that a behaviour was observed in an interval of 30 seconds of the four behaviours (Locomotion, Resting, Eating and Grooming) estimated at the two days (many visitors and few visitors) for ring-tailed lemurs (L. catta) and black lemurs (E. macaco) and p-values for the Wilcoxon rank sum tests.

Behaviour	***L. catta* (many visitors)**	***L. catta* (few visitors)**	**Wilcoxon-test**	**P value**
Locomotion	0.00	0.00	(many visitors) > (few visitors)	P < 0.001
Resting	0.17	1.00	(many visitors) < (few visitors)	P < 0.001
Eating	0.00	0.00	(many visitors) < (few visitors)	P < 0.001
Grooming	0.00	0.00	(many visitors) < (few visitors)	P < 0.001
	***E. macaco* (many visitors)**	***E. macaco* (few visitors)**		
Locomotion	1.00	1.00	(many visitors) > (few visitors)	P = 0.24
Resting	0.50	0.50	(many visitors) > (few visitors)	P < 0.01
Eating	0.00	0.00	(many visitors) < (few visitors)	P < 0.001
Grooming	0.00	0.00	(many visitors) < (few visitors)	P < 0.001

Machine Learning
Wilcoxon Rank Sum test

The Wilcoxon rank sum test shows a significantly ($p < 0.001$) higher locomotion activity for both species (*L. catta* and *E. macaco)* in the day with many visitors, compared with to the day with few visitors.

Boxplot

The boxplot comparing ring-tailed lemurs on the day with few and many visitors illustrates that they have a significantly higher median for locomotion on the day with many visitors compared to the day with few ($p_{wilcoxon}=7.215x10^{-13}$) (Figure 5a). The boxplot comparing black lemurs (*E. macaco)* on the day with many visitors compared to the day with few also shows that black lemurs has a significantly higher median ($p_{\mathrm{wilcoxon}} = 6.778 * 10^{-9}$) on the day with many visitors (Figure 5b).

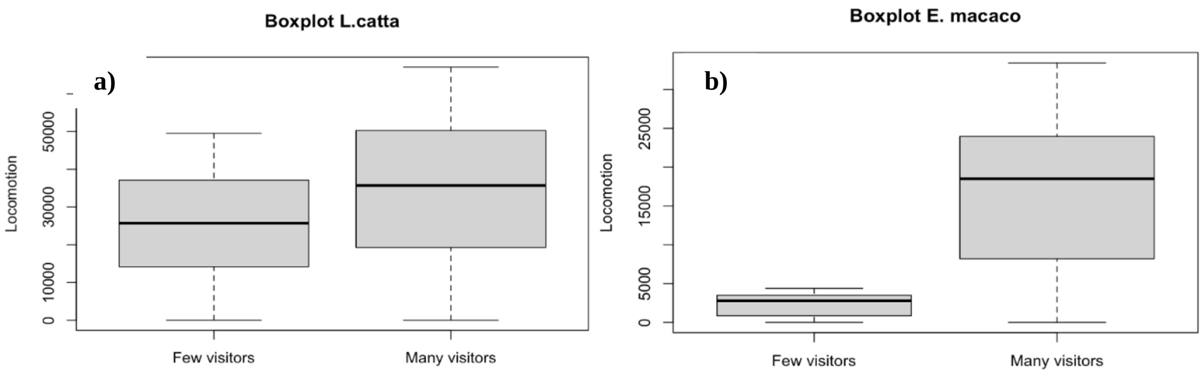

Figure 6. Boxplot over the results for locomotion (estimated as cumulative distance) from machine learning. a) ring-tailed lemurs (L. catta) and b) black lemurs (E. macaco) shows the two species by comparing the day with many and the day with few visitors.

The cumulative curves

The cumulative curves of the cumulative distance over time for both species on the two days also show clear evidence for higher locomotor activity, when there are many visitors. However, it is noteworthy that the differences in locomotor activity are increasing over time, which implies that in order to be able to observe differences it is necessary to register the activity over a certain period of time.

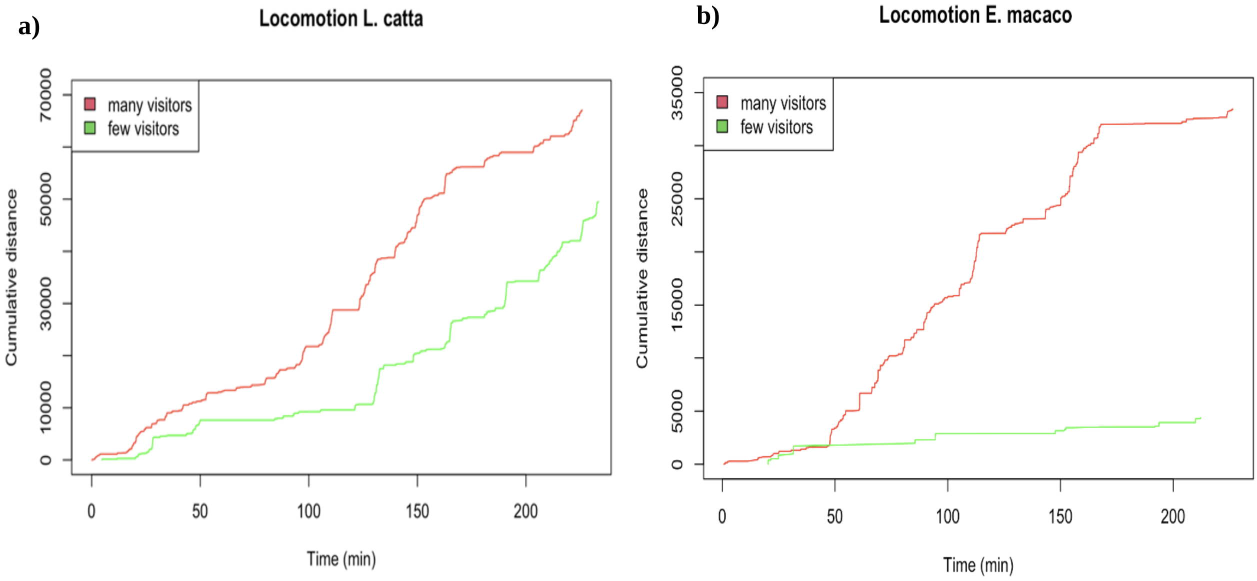

Figure 7. a) The cumulative distance over time for ring-tailed lemurs (L. catta) on the day with many (red) and the day with few (green) visitors and b) for black lemurs (E. macaco) on the day with many (red) and the day with few (green) visitors.

Discussion

The fact that the manually collected data of black lemurs did not show significant differences in 'locomotion' on the two days suggest that the they were not affected by visitors in relation to this behaviour. This is in agreement with Collins and Coworkers (2017) that studied free-ranging ring-tailed lemurs in a wildlife park in Ireland and only found minor effects of visitors on the behaviour of the lemurs. Goodenough and Coworkers (2019) also studied the behaviour of ring-tailed lemurs in a walk-through enclosure at a safari park in United Kingdom, and they found that time of day and weather were underlying factors, and that these accounted for a large part of the explanation of changes in behaviour during visitor interaction. In agreement, Collins and Coworkers (2017) concluded that time of day and weather have larger effects on the animal behaviour compared to visitor interaction. Collins and Coworkers (2017) found the lemurs to be more active in drier and warmer conditions. In future studies, more days with low/high numbers of visitors. It should be noted that the machine learning data showed slightly different results than the manual ones on this point. Data from the machine learning approach showed that many visitors present did have an impact on the two species' 'locomotion', as the lemurs exhibited more 'locomotion' on the day with many visitors. The reasons for these contrasting results could be that locomotion in the machine learning approach is quantified as the average distance travelled in an interval of 30 seconds, whereas the manual data collection quantify locomotion as the number of times that a behaviour was observed in an interval of 30 seconds. Both the manual and machine learning cumulative graphs showed that black lemurs had more locomotion on the day with many visitors compared to the day with few visitors. A study from Parco Zoo Punta Verde in Italy (Manna *et al.*, 2007) studied different lemur species in a walk-through enclosure during visitor interaction and found that there was an increase in terrestrial locomotion when visitors were present (Collins *et al.*, 2017). This could indicate that at least some lemur species are influenced by the number of visitors, and that black lemurs could be an example of that.

Zuerl and Coworkers (2022) were using video-based analysis framework to monitor polar bears at Nuremberg Zoo in Germany, and were testing if computer generated monitoring was more effective than manually monitoring to decode welfare of zoo animals. The polar bears' overall welfare was studied by video recordings and analysed by machine learning. They concluded that manual observation of zoo animals has the limitation that crucial observations are missing to draw the right conclusions. They found that machine learning is much less time consuming and gives the opportunity to monitor animals on a 24/7 basis, which gives a more accurate picture of animal welfare (Zuerl *et al.*, 2022). Since only two polar bears were observed in this study it is easy to make individual assessments from the data although polar bears usually lack prominent individual features. In our study it was not possible for the machine learning model to detect individual lemurs or detect different behaviours which is why only locomotion activity was considered for the machine learning approach. The machine learning model could, however, easily differentiate between the two species, correctly. The interior design of the enclosure is also an important factor that can affect the capacity of detection of machine learning. Trees, other plants etc. gave a lot of issues since the machine learning was not always able to detect and distinguish between lemurs and enclosure designs. It would be ideal to use machine learning detection on a few animals with distinctive individual visual features and in a setting where the animals stand out in the enclosure without too many potential confounding factors.

The two tested methodologies (manual collection of data and the machine learning) have both advantages and disadvantages. An advantage for manually collecting of data was that we were able to study more than one behaviour (locomotion) compared to the machine learning. However, machine learning could potentially be able to detect more behaviours such as 'grooming' or 'eating', but that would require more data, as all behaviours would have to be labeled enough times and from several angles. A disadvantage of the manual collection of behavioural data could be that the video material has been viewed by different operators, which potentially can cause bias in assessment and thereby results. Another disadvantage is that it is time-consuming to collect the data manually, and it is easy to miss a performed behaviour, as several lemurs must be viewed at the same time. An advantage of machine learning is that this process can be automatized. However, image recognition of locomotion was based on a two-dimensional coordinate system, giving only a two-dimensional view of the locomotion. This is a source of error, as movement on a third axis may be overlooked. To avoid this problem in future studies a third camera could be added to the z-plane. Although there are some disadvantages with machine learning, this approach will probably be the most used in the near future, where it will open a lot of opportunities to study different animal behaviours and welfare in zoo-housed animals.

Acknowledgements
We would like to thank the staff at Aalborg Zoo for allowing us to conduct this study. Thank you to Kasper Kystol Andersen, Technician at Aalborg Zoo, for helping us with accessing and using the video material. Finally, we would like to thank two anonymous Reviewers for invaluable suggestions and help which have improved the manuscript.

Funding Information
The study was funded by Aalborg Zoo Conservation Foundation (AZCF grant number 04-2023).

Author Contributions
All authors contributed equally to the manuscript; experimental design, writing and revison of the manuscript.

Conflict of Interest
The authors declare that there are no conflict of interests.

References

Collins, C., Corkery, I., Haigh, A., McKeown, S., Quirke, T., & Riordan, R. 2017. The effects of environmental and visitor variables on the behavior of free-ranging ring-tailed lemurs (*Lemur catta*) in captivity. *Zoo Biology*, *36*(4), 250-260.https://onlinelibrary.wiley.com/doi/abs/10.1002/zoo.21370

Goodenough, A. E., McDonald, K., Moody, K., & Wheeler, C. 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), 59-66. https://jzar.org/jzar/article/view/343

Hosey, G., Ward, S., & Melfi, V. 2023. The effect of visitors on the behaviour of zoo-housed primates: A test of four hypotheses. *Applied Animal Behaviour Science, 263, 105938* https://www.sciencedirect.com/science/article/abs/pii/S0168159123001107?casa_token=iQCgPRl7o_sAAAAA:coYgT9gSw_dF0uGQMYfA-TKLRhzmKaDUatjGdDkpkE-WnX2mdQiyYiKCH7frxFkYr3A-Q-q76A

Hvilsom, C., Welden, H. L. Å, Stelvig, M., Nielsen, C. K., Purcell, C., Eckley, L., & Bertelsen, M. F. 2020. The contributions of EAZA zoos and aquariums to peer-reviewed scientific research. *Journal of Zoo and Aquarium Research 8* (2), 133-138 https://doi.org/10.19227/jzar.v8i2.486

Kummrow, M. 2020. Diagnostic and therapeutic guidelines to abnormal behavior in captive nonhuman primates. *Veterinary Clinicics: Exotic Animal Practice 24, 235-266* https://www.vetexotic.theclinics.com/article/S1094-9194(20)30064-5/fulltext

Learmonth, M. J., Chiew, S. J., Godinez, A., & Fernandez, E. J. 2021. Animal-visitor interactions and the visitor experience: Visitor behaviors, attitudes, perceptions, and learning in the modern zoo. Animal Behaviour and Cognition 8 (4), 632-649 https://pdfs.semanticscholar.org/2e51/e0b4a818ad7a184663c1262c731411ac7d5a.pdf

Legendre, P., & Legendre, L. 1998. *Numerical Ecology* (Secound english edition ed.). Elsevier.

Lewis, R. N., Chang, Y., Ferguson, A., Lee, T., Clifforde, L., & Abeyesinghe, S. M. 2020. The effect of visitors on the behavior of zoo-housed western lowland gorillas (*Gorilla gorilla gorilla*). *Zoo Biology, 39* (5), 283-296. https://onlinelibrary.wiley.com/doi/abs/10.1002/zoo.21552?casa_token=_1mgGDldCfIAAAAA%3Ah-zBrahFHhhmbokC0WO9b6tyurIlV-Qzc5lwuV084km6FqWODdP8OtW5LtOU_HXfAJL19hpHTFQ1JA

Manna, D., Rodeano, M., & Ferrero, E. A. 2007. A lemur mixed exhibit at Parco Zoo Punta Verde, Italy. *International Zoo News, 54* (361), 452–457. http://hdl.handle.net/11368/1853569

Ross, S. R., Melber, L. M., Gillespie, K. L., & Lukas, K. E. 2012. The Impact of a Modern, Naturalistic Exhibit Design on Visitor Behavior: A Cross-Facility Comparison. https://www.tandfonline.com/doi/full/10.1080/10645578.2012.660838?scroll=top&needAccess=true

Sharma, S., Khanal, L., Shrestha, S., Pandey, N., Bellanca, R. U., & Kyes, R. C. 2023. Zoo visitors as a source of enrichment to reduce abnormal behavior in captive rhesus macaques (*Macaca mulatta*) in the Central Zoo, Kathmandu, Nepal. *Journal of Animal Behaviour and Biometeorology* 11 (1), e20233005 https://doi.org/10.31893/jabb.23005

Sherwen, S. L., & Hemsworth, P. H. 2019. The visitor effect on zoo animals: Implications and opportunities for zoo animal welfare. *Animals, 9* (6), 366 The Visitor Effect on Zoo Animals: Implications and Opportunities for Zoo Animal Welfare - PMC (nih.gov)

Sherwen, S. L., Hemsworth, P. H., Butler, K., Fanson, K. V., & Magrath, M. J. L. 2015. Impacts of visitor number on Kangaroos housed in free-range exhibits: Kangaroo welfare in free-range exhibits. *Zoo Biology* 34 (4), 287-295 https://www.researchgate.net/publication/277725459_Impacts_of_visitor_number_on_Kangaroos_housed_in_free-range_exhibits_Kangaroo_Welfare_in_Free-Range_Exhibits

Warsaw, D., & Sayers, J. (2020). The influence of animal welfare accreditation programs on zoo visitor perceptions of the welfare of zoo animals. *Journal of Zoo and Aquarium Research* 8 (3), 188-193 https://www.jzar.org/jzar/article/view/401/325

Williams, E., Carter, A., Rendle, J., & Ward, S. J. 2021. Understanding impacts of zoo visitors: Quantifying behavioural changes of two popular zoo species during COVID-19 closures. *Applied Animal Behavioral Science* 236, 105253 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9755048/

Zhao, Z.-Q., Zheng, P. , Xu S.-T. & Wu, X. 2019. "Object Detection With Deep Learning: A Review," *IEEE Transactions on neural networks and learning systems*, vol. 30, no. 11, pp. 1-21, 11. https://www.researchgate.net/publication/330708842_Object_Detection_With_Deep_Learning_A_Review

Zhou, Z.-H. 2016 "Application Status," in *Machine Learning*, Singapore, Springer Nature, pp. 15-18.

Zuerl, M., Stoll, P., Brehm, I., Raab, R., Zanca, D., Kabri, S., Happold, J., Nille, H., Prechtel, K., Wuensch, S., Krause, M., Seegerer, S., von Fersen, L., & Eskofier, B. 2022. Automated video-based analysis framework for behavior monitoring of individual animals in zoos using deep learning—A study on polar bears. *Animals (Basel), 12*(6), 692. https://www.ncbi.nlm.nih.gov/pubmed/35327089

Appendix

Appendix 1

Overview of the number of visitors in the enclosure at a given time. Day one is considered the day with many visitors. Day two is a day with few visitors. The x-axis is time in minutes and the y-axis is the number of visitors in the enclosure.

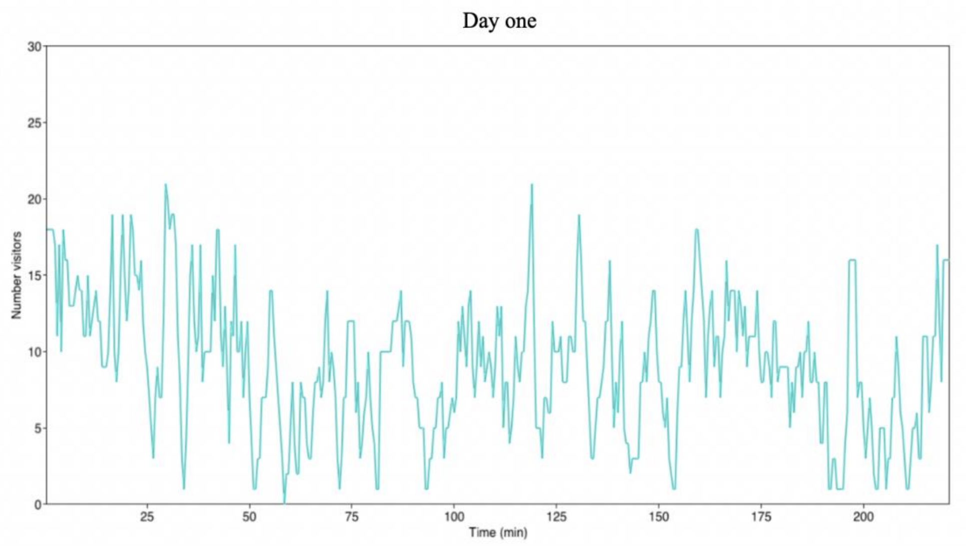

Figure a. Number of visitors (registered between 11 AM and 3 PM) in the enclosure on the day with many visitors (1,031 visitors on October 19th, 2023). The y-axis shows the number of visitors, and the x-axis shows time.

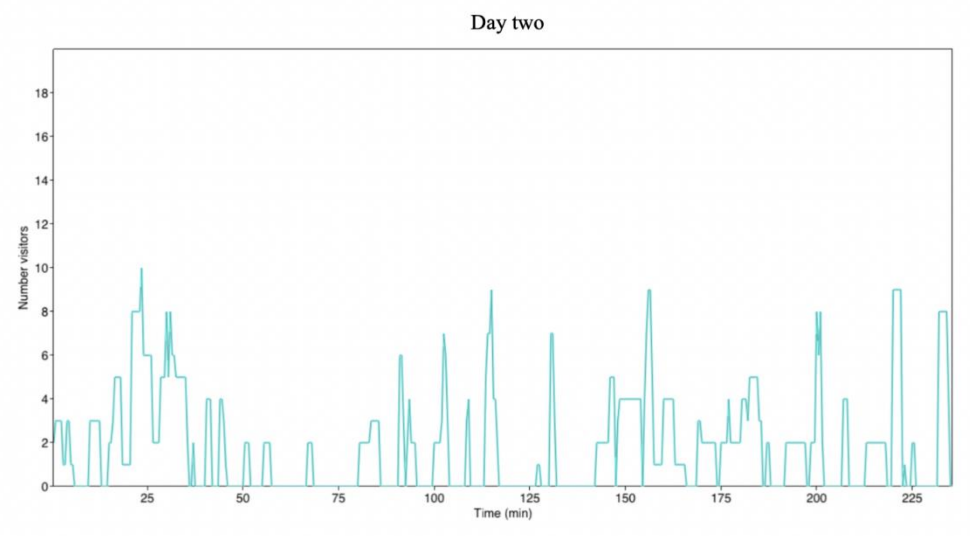

Figure b. Number of visitors (registered between 11 AM and 3 PM) in the enclosure on the day with few visitors (181 visitors on October 24th, 2023). The y-axis shows the number of visitors, and t