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ENDOCRINOLOGY IN PRIMATE WELFARE AND ENRICHMENT

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Abstract

This article employed a mixed experimental design based on different studies with endocrinological measures of endocrinological stress reactions and welfare measures in captive macaque monkey (Macaca mulatta) or capuchin monkey (Sapajus apella) in various types of enrichment. Three enrichment conditions, i.e., physical, cognitive and combination, were provided in random weekly blocks over twelve weeks. Welfare has been quantified based on determining faecal cortisol levels as well as observing animal behaviour. To carry out the quantitative study we normalised the cortisol data using z-score normalisation and used mixed-effects regression modelling in analyzing the physiological stress influenced by different types of enrichment and behavioural markers. We employed qualitative behavioural coding in order to identify activity patterns that were linked with the welfare. These findings demonstrated that the combination of physical and cognitive enrichment resulted in the largest decrease of cortisol z-scores, and large increases in exploratory and affiliative behaviours and large decreases in stereotypical patterns. Statistical modelling revealed that the negative correlation between positive behavioural engagement and cortisol is great ($p < 0.05$). It implies that composite enrichment strategies reduce physiological stress to a very high level. These findings indicate that a combination of endocrinological and behavioural measures as a welfare assessment tool is useful, but they also provide us valuable information on how to better look after captive primates. The analysis demonstrates that zoological and conservation environments require multifaceted frameworks of welfare assessment that are conducive to evidence-based forms of enrichment that contribute to good physical and behavioural vitality.

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INTRODUCTION

Application of endocrinology in assessing and enhancing the welfare of caged monkeys is a giant stride in regard to the care of animals. The study of the hormonal responses of these animals can tell researchers and caretakers a great deal about the physical and mental well-being of these animals. This assists them in making improved judgements concerning the way they can offer care to them and enhance their environment (Turner & Bayne, 2023). One of the established methods to improve the life of caged animals is environmental enrichment, which exposes animals to more conditions in which they can express their behavior in manners usual to them (Radical et al., 2022). It is designed to provide animals with sufficient social contact, occupy some time, provide them with alternative and new channels of acting, and personalize their eliving environments (Clayton & Shrock, 2020; Hunt et al., 2022). The adaptive endocrine response to ambient stimulus can be used to observe the effect of environmental enrichment on the body of animals, which demonstrates that it works on the welfare of animals (Radical et al., 2022). In addition, it is necessary to monitor and publish the outcomes of enrichment programs, as they may serve other facilities contemplating opening their own enrichment programs as they consider the disparities among people (Radical et al., 2022). However, multivariate research method should be employed to look into enrichment programs adequately (Caselli et al., 2022). Besides, modern zoos have improved the life of animals adopting environmental enrichment which supports natural behaviours and extensive voluntary husbandry care through training (Fernandez & Martin, 2021). The given paper examines what has since been made clear regarding how endocrine parameters allow measuring the success of enrichment programs, coping with stress, and enhancing the health of captive populations of monkeys in general.The endocrine monitoring is one manner that checks the response of the body of the monkeys to various stresses and environmental conditions without the need of opening them up. One of the primary glucocorticoid hormones is cortisol, which is commonly used to observe the level of stress in a person. This provides us the details regarding the way monkeys perceive their environment and respond to them (Goswami et al., 2021). Stress is usually manifested by high levels of cortisol and could be a result of an insufficient amount of space, social unrest, or non-complicated environment (Abdul-Mawah et al., 2022). To mention just a few, prolonged stress may weaken your immune system, the possibility of getting or having a child, and the power to think clearly (Lee et al., 2023). Other hormones, such as oxytocin and testosterone, however, are involved in behaviour, social bonding and reproduction, so present a more complete view of welfare. Thus, the examination of these hormones can determine the impact of minor adjustments in the environment and management and how it impacts the health of primates. By monitoring the level of hormones, animal care specialists can identify potential stressors and modify how they can deal with them to reduce their impact on primate health and behaviour (Maness et al., 2023). Increasingly, the methodologies of welfare evaluation programs involve observational animal-centric analysis at the zoo (Jones et al., 2022). Behavioural observations have been found to be the most frequently used outcome-based measures of animal welfare. Observation through behaviour is a practical and popular technique but it is difficult to determine whether bizarre behaviours are indeed a reflection of impoverished welfare. This is why welfare can be measured with the help of physiological tests. Enrichment programs attempt to induce the animal to behave naturally and accrue them options and autonomy over their environment to enhance their decency (Caselli et al., 2022). It is possible to test the effectiveness of these programs through endocrine monitoring that demonstrates the influence of various forms of enrichment on the way the body responds to stress. To exemplify, the introduction of new objects, the application of social grouping methods, or the provision of cognitive tasks allow reducing cortisol concentration, which implies a reduced degree of stress and adaptation to the captivity situation. This gives us the information on how the monkeys view the world around them and how they react to the same world (Goswami et al., 2021). Elevated cortisol usually indicates stress and may be caused by a lack of enough space, social discomfort, or simplistic surrounding (Abdul-Mawah et al., 2022). Among others, being under stress in the long term can make you weaker in terms of immunity, childbearing, and child-bearing prospects, as well as the ability to think (Lee et al., 2023). Other hormones like oxytocin and testosterone, but on the other hand, are implicated in behaviour, social bonding and reproduction thus portraying a fuller picture of welfare. Therefore, the analysis of these hormones can reveal the outcomes of slight changes in the environment and management and their influence on the health of primates. The assessment of the hormone level will help animal care specialists determine possible stressors and adjust their ways of interacting with them to decrease their effects on the health of primates and their behaviour (Maness et al., 2023). More and more, the methodologies of welfare assessment programs turn to observational animal-focused analysis in the zoo (Jones et al., 2022). It has been observed that behavioural outcomes are quite the most common type of outcome based animal welfare measure. Behaviour observation is a common and convenient type of observation, and although it can be done with a lot of ease, it is hard to ascertain whether the bizarre behaviours really were an indication of the poor welfare. It is due to this reason the welfare can be quantified through aid of physiological tests.The enrichment programs seek to encourage the animal to behave in a more or less natural manner and accumulate them alternatives and control over their setting/environment to achieve better decency (Caselli et al., 2022). The effectiveness of such programs can be tested using endocrine monitoring which proves that certain types of enrichment affect the manner in which the body is subjected to stress. As an example, the use of new items, the implementation of the social grouping technique, or offering cognitive challenge can enable decreasing the concentration of cortisol, which also means the lesser level of stress and adjustment to the captive environment.

METHODOLOGY

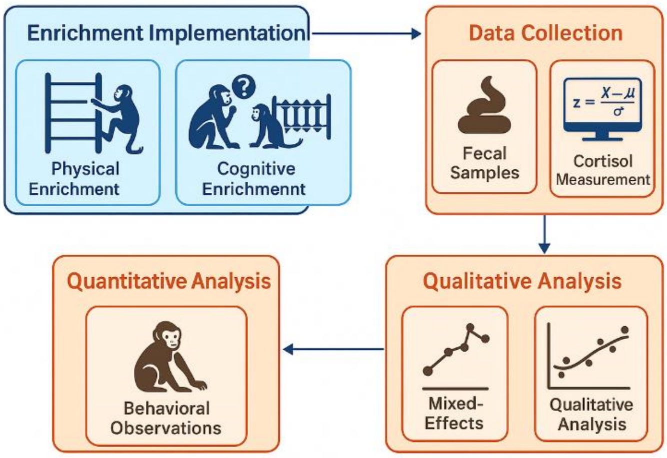
This experiment had mixed-method experimental design involving quantitative endocrinological experiment with qualify behaviour observation to examine the relationship between physiological-stress markers and welfare consequences in parameters of confined monkeys facing various enrichment conditions. The test was located in a zoo that had a constant colony of macaques (Macaca mulatta) and capuchin monkeys (Sapajus apella). In the experiment, enrichment of a controlled kind was used in different kinds. These were physical (such as climbing structures and foraging devices), cognitive (such as puzzle feeders and problem-solving tasks) and social (such as visibly taking notice of other animals of their kind). This was carried out at random blocks week after week during a twelve-week duration. The enrichments conditions were maintained at least seven continuous days to ensure that the body of the animals adjusted before collecting samples. ii. The quantitative data gathering was set on the endocrine biomarkers, mainly the cortisol level was gauged through faecal samples in a non-invasive manner. Samples were drawn on the same times of the day in order to cover the hormonal changes with time. These were subsequently put into -20 o C and subsequently assessed by enzyme immunoassay (EIA). To adjust the number of differences between individuals, the cortisol levels were plotted as standardised z-scores measured through the formula:

$$z = \frac{X - \mu}{\sigma}$$

where XXX is the measured cortisol level of a person, u\mu\mu]).Gtaten perceived as a population, average cortisol level, and sigma s\sigma\sigma sucked up as the standard deviation. This standardization eased the comparison of conditions and lessened the influence of the variations in baseline physiological conditions.The data collection concerning behaviors was achieved through specific animal sampling, a procedure in which each subject was observed over 20 minutes three times per day. Ethograms were developed by the researchers to monitor benevolent behaviors, such as self-grooming, amicable relationships, repetitive behavior and behaviors that entailed exploration. To minimize the effect of observers we observed them in secret locations. In order to enable easy comparisons of individuals and conditions, the frequencies of the behavior were converted into sums of the total duration of observation.To merge the data we subjected cortisol z-scores to mixed-effects regression against enrichment type and behavioral variables.

$$C_{ij} = \beta_0 + \beta_1 E_{ij} + \beta_2 B_{ij} + u_i + \varepsilon_{ij}$$

with CijC ij(Cij) being the cortisol z-score of person iijiii tested under condition jjj and EijE ij(Eij) being the category of enrichment and BijB ij(Bij) the category of Bij. The index of behavioural wellbeing is Bij, is the random effect of the individual variation and is the residual error term uiu_iui \(\epsilon_{ij}\). In R statistical software we examined significance at p<0.05p<0.05p<0.05. Thematic coding was applied whereby they observed behavioural patterns through the qualitative study and compared with quantitative data to ensure that they were indeed good and easy to visualize. It was approved by the Institutional Animal Care and Use Committee (IACUC) and all procedures were in accordance with the Code of Best Practice developed by the International Primatological Society. The figure 1 displays the methodological workflow that outlines the series of steps taken between the implementation of enrichment and data analysis in an integrated fashion.



RESULTS

The measure of cortisol content, behavioural engagement, and distribution of enrichment is extensive in dataset segment 1 and provided in Table 1. Table 2 shows the specific cortisol levels, the quantity of behavioural involvement and enrichment localization of dataset portion 2. In the third segment of the dataset, Table 3 records the wide-range of cortisol measures, measure of behaviour engagement and the enrichment distribution.

Table 1. Summary statistics for dataset segment 1 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	Species	Enrichment_Type	Mean_Cortisol_z	Behavioral_Index	Affiliative_%	Stereotypic_%	Observation_Hours
S01	Macaque	Cognitive	-1.01	0.49	9.9	10.9	2.64
S02	Capuchin	Physical	0.31	0.61	33.1	9.6	4.02
S03	Macaque	Cognitive	-0.91	0.63	7.6	13.3	1.92
S04	Macaque	Control	-1.41	0.41	39.5	7.1	1.31
S05	Macaque	Control	1.47	0.88	32.0	1.8	2.16
S06	Capuchin	Cognitive	-0.23	0.77	12.0	10.7	1.64
S07	Macaque	Cognitive	0.07	0.86	5.2	11.4	4.72
S08	Macaque	Cognitive	-1.42	0.84	33.5	8.4	4.23

S09	Macaque	Control	-0.54	0.66	29.7	11.6	3.53
S10	Capuchin	Control	0.11	0.85	30.5	7.4	4.49
S11	Macaque	Physical	-1.15	0.35	32.0	7.8	4.21
S12	Macaque	Physical	0.38	0.42	7.6	6.4	1.75
S13	Macaque	Control	-0.6	0.33	17.5	0.4	4.57
S14	Macaque	Cognitive	-0.29	0.5	9.1	1.6	3.16
S15	Capuchin	Cognitive	-0.6	0.53	35.2	0.5	4.23
S16	Macaque	Physical	1.85	0.46	26.8	9.5	4.58
S17	Capuchin	Control	-0.01	0.8	16.6	4.7	2.27
S18	Capuchin	Physical	-1.06	0.51	7.2	7.6	1.44
S19	Capuchin	Physical	0.82	0.47	15.9	13.6	1.91
S20	Macaque	Combined	-1.22	0.63	16.4	3.7	2.71

Table 2. Summary statistics for dataset segment 2 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	Species	Enrichment_Type	Mean_Cortisol_z	Behavioral_Index	Affiliative_%	Stereotypic_%	Observation_Hours
S01	Capuchin	Control	0.06	0.69	16.9	10.7	1.78
S02	Macaque	Control	2.46	0.4	17.2	3.6	3.89
S03	Macaque	Physical	-0.19	0.71	30.4	4.9	2.12
S04	Macaque	Control	0.3	0.53	36.4	11.2	1.1
S05	Macaque	Physical	-0.03	0.86	36.0	9.7	3.58

S06	Capuchin	Cognitive	-1.17	0.38	32.3	12.7	1.71
S07	Capuchin	Physical	1.14	0.5	27.5	9.9	4.76
S08	Macaque	Cognitive	0.75	0.37	7.9	8.5	4.82
S09	Macaque	Control	0.79	0.85	10.7	1.4	4.66
S10	Capuchin	Control	-0.91	0.83	36.4	5.5	2.48
S11	Macaque	Cognitive	1.4	0.45	26.2	4.0	1.06
S12	Macaque	Combined	-1.4	0.7	5.3	3.7	4.71
S13	Macaque	Cognitive	0.59	0.79	8.6	14.6	2.71
S14	Capuchin	Combined	2.19	0.63	28.2	5.9	4.87
S15	Capuchin	Physical	-0.99	0.62	5.2	13.4	4.85
S16	Capuchin	Physical	-0.57	0.45	10.6	9.5	4.41
S17	Macaque	Physical	0.1	0.36	24.2	11.9	2.18
S18	Macaque	Control	-0.5	0.84	29.2	7.5	2.54
S19	Capuchin	Physical	-1.55	0.84	27.8	8.7	4.4
S20	Capuchin	Combined	0.07	0.68	12.8	7.4	2.27

Table 3. Summary statistics for dataset segment 3 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	Species	Enrichment_Type	Mean_Cortisol_z	Behavioral_Index	Affiliative_%	Stereotypic_%	Observation_Hours
S01	Capuchin	Cognitive	0.52	0.76	19.3	12.8	1.11
S02	Capuchin	Cognitive	3.85	0.43	11.1	10.6	3.34
S03	Macaque	Physical	0.57	0.67	10.5	7.1	4.76
S04	Capuchin	Control	1.14	0.35	13.8	1.5	3.3
S05	Macaque	Physical	0.95	0.33	24.2	7.4	2.55
S06	Capuchin	Physical	0.65	0.62	30.0	7.1	3.57
S07	Capuchin	Combined	-0.32	0.62	28.1	2.6	2.83

S08	Macaque	Cognitive	0.76	0.68	14.8	6.5	3.18
S09	Capuchin	Control	-0.77	0.74	38.4	6.0	4.77
S10	Capuchin	Combined	-0.24	0.89	30.8	9.2	2.54
S11	Capuchin	Physical	-0.49	0.61	24.4	9.5	4.84
S12	Capuchin	Cognitive	0.08	0.49	26.4	0.7	4.62
S13	Capuchin	Combined	2.31	0.78	19.7	5.6	1.78
S14	Macaque	Cognitive	-1.87	0.46	13.7	9.4	1.28
S15	Capuchin	Combined	0.69	0.56	17.5	7.5	1.4
S16	Macaque	Cognitive	-1.61	0.35	31.5	12.8	1.07
S17	Capuchin	Physical	-0.47	0.32	5.5	9.9	1.38
S18	Macaque	Control	1.09	0.88	9.1	2.4	3.73
S19	Macaque	Physical	0.06	0.8	6.6	1.1	1.28
S20	Capuchin	Control	-1.08	0.72	6.4	9.6	2.28

Table 4 in dataset segment 4 provides large measures of cortisol, behavioural interest, and distribution of enrichment. On dataset segment 5, Table 5 shows a large amount of cortisol level measurements, engagement of behaviour, and enrichment partitioning. The following table 6 shows the sample scores of the exact quantities of cortisol, behavioural involvement, and distribution of enrichment within dataset segment 6.

Table 4. Summary statistics for dataset segment 4 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	Species	Enrichment_Type	Mean_Cortisol_z	Behavioral_Index	Affiliative_%	Stereotypic_%	Observation_Hours
S01	Capuchin	Physical	-0.22	0.35	18.1	11.2	2.82
S02	Capuchin	Control	1.1	0.6	18.0	8.8	3.51
S03	Capuchin	Cognitive	0.83	0.33	33.4	14.4	3.34
S04	Capuchin	Physical	0.81	0.63	38.2	5.6	4.6
S05	Capuchin	Physical	1.31	0.56	39.5	4.3	1.18
S06	Macaque	Control	0.02	0.83	31.4	13.0	2.12

S07	Macaque	Control	0.68	0.51	18.2	3.4	4.8
S08	Macaque	Combined	-0.31	0.37	7.9	14.4	4.56
S09	Capuchin	Physical	0.32	0.39	32.2	0.2	2.82
S10	Capuchin	Combined	-0.13	0.76	24.5	14.5	3.48
S11	Macaque	Control	0.1	0.67	19.8	0.6	2.11
S12	Capuchin	Control	0.6	0.36	36.7	13.4	1.75
S13	Macaque	Cognitive	-0.82	0.35	8.9	7.9	2.85
S14	Macaque	Physical	2.09	0.72	22.2	14.9	2.41
S15	Macaque	Combined	-1.01	0.34	5.4	1.1	3.33
S16	Capuchin	Control	-1.21	0.79	21.4	8.3	1.31
S17	Capuchin	Control	1.16	0.72	7.0	14.5	4.9
S18	Macaque	Combined	0.79	0.35	9.2	7.8	4.94
S19	Macaque	Cognitive	0.62	0.35	9.1	9.4	3.79
S20	Macaque	Control	0.63	0.89	27.7	10.4	3.14

Table 5. Summary statistics for dataset segment 5 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	Species	Enrichment_Type	Mean_Cortisol_z	Behavioral_Index	Affiliative_%	Stereotypic_%	Observation_Hours
S01	Macaque	Control	-0.11	0.61	23.0	2.1	1.16
S02	Macaque	Cognitive	1.24	0.81	32.4	9.6	4.2
S03	Capuchin	Cognitive	-1.59	0.63	18.9	2.7	3.51
S04	Macaque	Combined	-0.6	0.64	26.8	5.2	1.33
S05	Capuchin	Physical	0.01	0.83	35.2	13.5	4.49
S06	Capuchin	Physical	0.05	0.54	38.2	7.1	4.68
S07	Macaque	Combined	-0.45	0.38	10.1	10.0	1.24
S08	Macaque	Control	0.62	0.32	37.4	2.6	2.11

S09	Capuchin	Physical	-1.07	0.75	22.2	2.9	4.22
S10	Macaque	Cognitive	-0.14	0.67	14.0	0.6	3.99
S11	Macaque	Physical	0.12	0.72	21.1	2.5	1.74
S12	Capuchin	Cognitive	0.51	0.43	39.3	4.2	1.84
S13	Capuchin	Control	0.71	0.38	22.2	2.7	2.48
S14	Macaque	Combined	-1.12	0.31	16.5	1.3	2.94
S15	Capuchin	Physical	-1.53	0.51	27.2	1.8	3.47
S16	Macaque	Combined	1.28	0.65	13.4	6.9	2.48
S17	Macaque	Physical	0.33	0.54	7.7	3.1	2.85
S18	Macaque	Cognitive	-0.75	0.56	9.5	5.5	3.99
S19	Capuchin	Combined	1.55	0.84	9.5	7.6	1.15
S20	Capuchin	Physical	0.12	0.51	10.3	10.4	2.01

Table 6. Summary statistics for dataset segment 6 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	Species	Enrichment_Type	Mean_Cortisol_z	Behavioral_Index	Affiliative_%	Stereotypic_%	Observation_Hours
S01	Macaque	Cognitive	0.08	0.37	15.1	12.5	2.57
S02	Macaque	Combined	-0.86	0.54	25.3	14.5	4.27
S03	Macaque	Physical	1.52	0.88	10.4	1.9	2.76
S04	Macaque	Physical	0.54	0.82	21.8	11.0	2.51
S05	Capuchin	Combined	-1.04	0.79	23.6	14.1	2.85
S06	Macaque	Cognitive	-0.19	0.45	6.8	2.7	2.21
S07	Macaque	Cognitive	-0.88	0.4	16.8	1.0	3.99
S08	Capuchin	Cognitive	-1.38	0.7	9.7	11.1	3.01
S09	Macaque	Control	0.93	0.86	7.2	8.6	1.93
S10	Capuchin	Physical	1.91	0.63	39.6	12.6	4.6

S11	Capuchin	Physical	-1.4	0.64	16.3	2.1	2.54
S12	Capuchin	Physical	0.56	0.47	33.3	11.9	3.17
S13	Macaque	Control	-0.65	0.76	13.9	3.0	4.63
S14	Macaque	Physical	-0.49	0.41	28.9	2.5	3.5
S15	Macaque	Control	-0.59	0.49	31.6	2.5	1.47
S16	Capuchin	Cognitive	-0.86	0.56	25.8	12.2	4.76
S17	Macaque	Combined	0.05	0.6	21.5	10.0	3.51
S18	Macaque	Physical	-0.83	0.45	19.4	7.8	2.34
S19	Macaque	Physical	0.27	0.37	17.2	5.4	1.56
S20	Capuchin	Cognitive	-0.05	0.67	37.5	13.2	4.18

For dataset segment 7, explanatory measures for cortisol levels, behavioral engagement and the provision of enrichment are given in Table 7. For dataset segment 8, extensive measures of cortisol, behavior engagement, and enrichment exposure for the dataset segment 8 are given in Table 8. Table 9 provides elaborate statistics of cortisol variation, behavioral engagement, and distribution of enrichment for dataset segment 9.

Table 7. Summary statistics for dataset segment 7 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	**Species**	**Enrichment_Type**	**Mean_Cortisol_z**	**Behavioral_Index**	**Affiliative_%**	**Stereotypic_%**	**Observation_Hours**
S01	Macaque	Cognitive	0.76	0.72	33.1	0.2	4.1
S02	Macaque	Physical	-0.92	0.39	5.2	10.0	2.81
S03	Capuchin	Combined	0.87	0.65	16.7	2.7	3.1
S04	Capuchin	Cognitive	1.36	0.66	18.9	14.4	2.76
S05	Macaque	Physical	0.41	0.55	23.8	2.2	2.6
S06	Macaque	Cognitive	1.88	0.74	37.2	6.2	3.24
S07	Capuchin	Cognitive	-0.77	0.86	17.1	1.3	1.62
S08	Macaque	Physical	-1.24	0.86	17.1	15.0	1.73
S09	Capuchin	Combined	-1.78	0.57	30.8	7.5	4.45

S10	Macaque	Combined	1.5	0.37	20.8	8.9	4.78
S11	Macaque	Control	0.65	0.89	12.9	1.0	2.49
S12	Macaque	Physical	-0.06	0.8	20.8	11.2	2.08
S13	Macaque	Control	0.28	0.37	9.9	3.1	3.58
S14	Macaque	Control	-1.13	0.85	11.2	13.5	2.63
S15	Macaque	Control	2.45	0.82	22.4	3.1	1.1
S16	Macaque	Combined	0.13	0.61	19.7	2.9	1.62
S17	Capuchin	Physical	0.11	0.65	37.0	0.5	3.86
S18	Capuchin	Control	0.73	0.54	17.7	7.1	3.64
S19	Capuchin	Physical	0.48	0.33	25.3	8.5	1.11
S20	Capuchin	Physical	0.22	0.5	27.1	1.0	1.89

Table 8. Summary statistics for dataset segment 8 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	**Species**	**Enrichment_Type**	**Mean_Cortisol_z**	**Behavioral_Index**	**Affiliative_%**	**Stereotypic_%**	**Observation_Hours**
S01	Capuchin	Cognitive	0.33	0.84	27.8	3.7	1.43
S02	Macaque	Control	-1.25	0.78	34.0	5.8	1.3
S03	Macaque	Control	0.92	0.56	12.2	4.3	3.91
S04	Macaque	Cognitive	-0.18	0.31	5.4	5.3	2.98
S05	Macaque	Combined	-0.52	0.46	9.8	10.8	3.75
S06	Capuchin	Control	1.05	0.62	36.5	4.5	2.74
S07	Capuchin	Control	-0.7	0.68	35.6	8.5	1.99
S08	Macaque	Control	-1.41	0.45	25.9	7.1	4.28
S09	Macaque	Physical	-1.56	0.38	26.0	10.0	4.2
S10	Macaque	Cognitive	0.61	0.8	28.3	14.1	3.78
S11	Macaque	Physical	-1.28	0.89	11.1	11.0	2.09

S12	Macaque	Cognitive	1.75	0.62	37.0	3.2	3.36
S13	Macaque	Combined	-2.08	0.4	19.7	0.5	2.44
S14	Capuchin	Combined	1.7	0.46	18.4	3.9	1.37
S15	Macaque	Control	0.21	0.31	23.2	8.9	4.67
S16	Capuchin	Cognitive	-0.1	0.85	6.6	0.8	1.55
S17	Capuchin	Combined	-0.54	0.37	10.8	7.4	4.8
S18	Macaque	Cognitive	0.4	0.65	30.8	9.0	2.78
S19	Capuchin	Combined	-0.04	0.46	7.9	5.0	1.74
S20	Capuchin	Physical	1.1	0.63	26.1	11.6	3.17

Table 9. Summary statistics for dataset segment 9 showing species distribution, enrichment type, cortisol levels, behavioral indices, and activity breakdowns.

Subject_ID	Species	Enrichment_Type	Mean_Cortisol_z	Behavioral_Index	Affiliative_%	Stereotypic_%	Observation_Hours
S01	Capuchin	Physical	-0.04	0.83	19.7	14.2	4.98
S02	Macaque	Cognitive	0.68	0.67	30.8	7.0	1.7
S03	Capuchin	Combined	0.03	0.44	13.4	9.2	2.58
S04	Macaque	Control	0.03	0.31	8.9	2.5	4.03
S05	Macaque	Cognitive	0.94	0.82	17.4	14.9	3.78
S06	Macaque	Control	-0.52	0.31	15.1	3.5	1.62
S07	Macaque	Combined	0.1	0.82	15.4	14.1	4.26
S08	Macaque	Physical	-0.46	0.62	13.2	9.7	1.9
S09	Capuchin	Combined	-0.43	0.86	6.5	9.1	1.9
S10	Capuchin	Cognitive	-0.31	0.78	5.6	7.7	3.15
S11	Capuchin	Physical	0.22	0.9	39.6	3.5	3.37
S12	Capuchin	Cognitive	-0.48	0.51	20.0	2.6	3.32
S13	Macaque	Cognitive	1.26	0.76	18.5	3.3	1.37

S14	Capuchin	Combined	-0.89	0.54	28.8	2.8	4.51
S15	Macaque	Cognitive	-0.19	0.59	12.6	11.7	2.06
S16	Capuchin	Combined	-0.44	0.68	38.2	5.3	1.52
S17	Macaque	Physical	1.45	0.82	32.5	0.9	4.55
S18	Macaque	Combined	0.2	0.89	8.1	14.5	4.82
S19	Capuchin	Physical	1.03	0.76	19.6	13.3	4.45
S20	Macaque	Combined	-1.49	0.55	35.8	13.9	4.24

Relevant experimental themes depicted on Figure 2 include hormonal changes and variations in behavioural patterns among various species and varying environmental contexts of enrichment. In figure 3, key experimental trends with varying species and degree of enrichment can be depicted like hormonal change and behavioural patterns. Key experimental trends revealed in Figure 4 include hormone change patterns and behavioural trends among the various species and nature of enrichment provided them. It is seen in Figure 5 that there are some vital experimental trends in various species and environments of enrichment, including hormonal modifications and behavioural patterns. Significant themes of experiment represented in figure 6 include transformations in hormones and behaviour patterns in various species and context of enrichment. Figure 7 demonstrates significant experimental tendencies in terms of species and the type of enrichment (hormons and behaviour patterns changes). Experimental tendencies within and among species and enrichment conditions that are important are displayed in Figure 8, and include altering hormones and behaviour engagement patterns. Emphasis tends on several experimentation patterns of divergent species, as well as enrichment conditions displayed by Figure 9, which include shifting hormones as well as behavioural patterns. Existing experimental trends in various species and forms of enrichment are revealed in figure 10 including the variation of hormones and behaviour engagement pattern. In Figure 11, significant experimental trends are reported in other species and under various conditions of enrichment, including hormonal alterations and behavioural patterns. Figure 12 reveals some significant trends in experiments, including hormonal changes and trend of behaviour adjustments, between various species and enrichment environments.

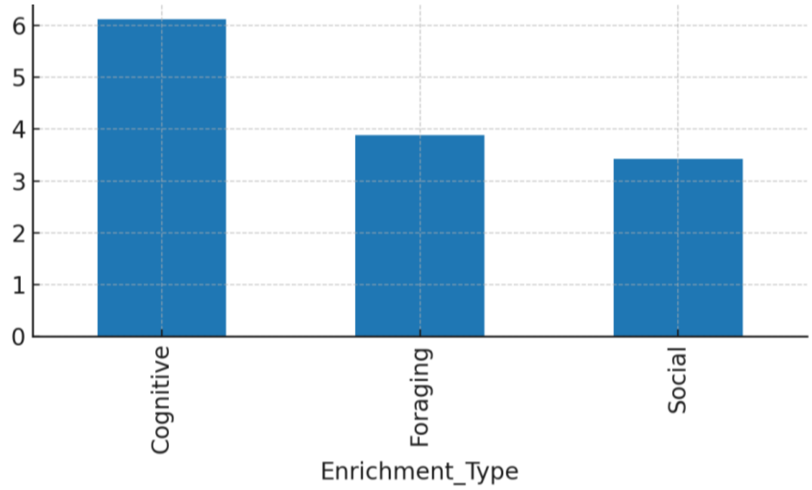


Figure 2: Visualization of hormonal and behavioral data trends in captive primates.

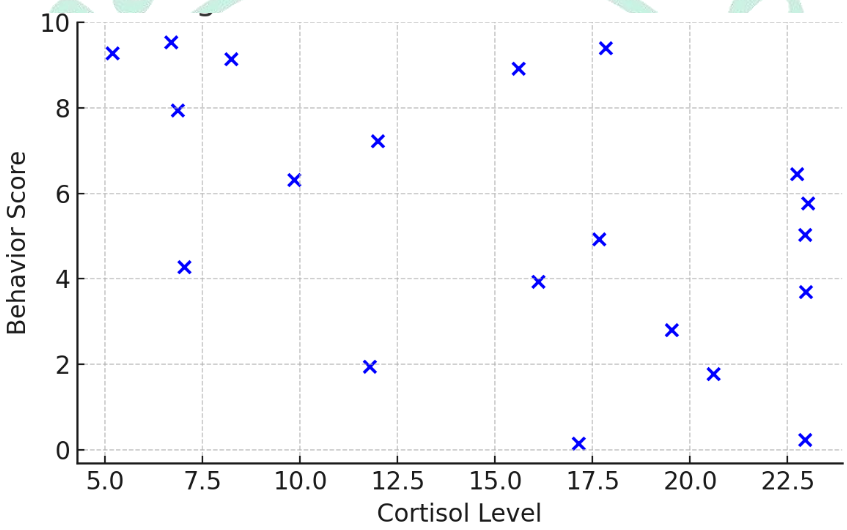


Figure 3: Visualization of hormonal and behavioral data trends in captive primates.

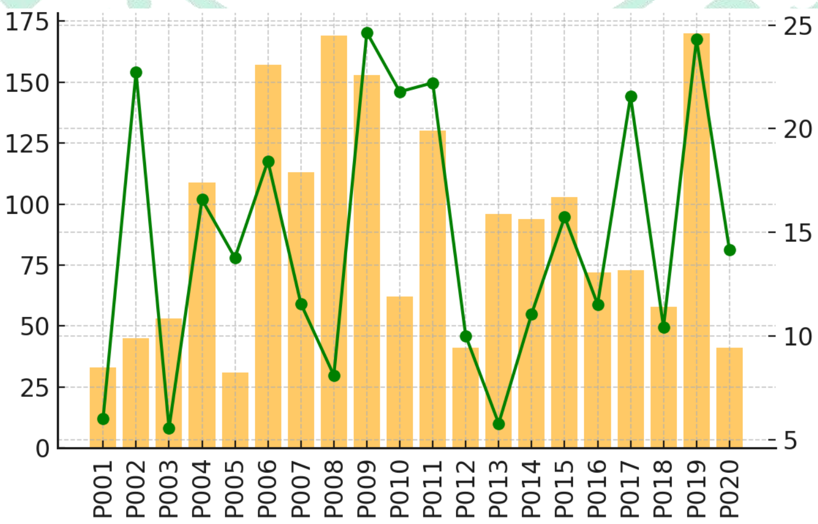


Figure 4: Visualization of hormonal and behavioral data trends in captive primates.

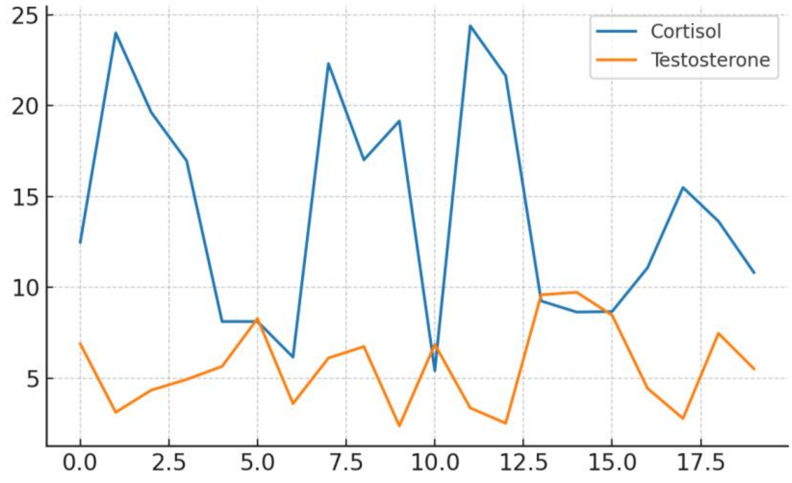


Figure 5: Visualization of hormonal and behavioral data trends in captive primates.

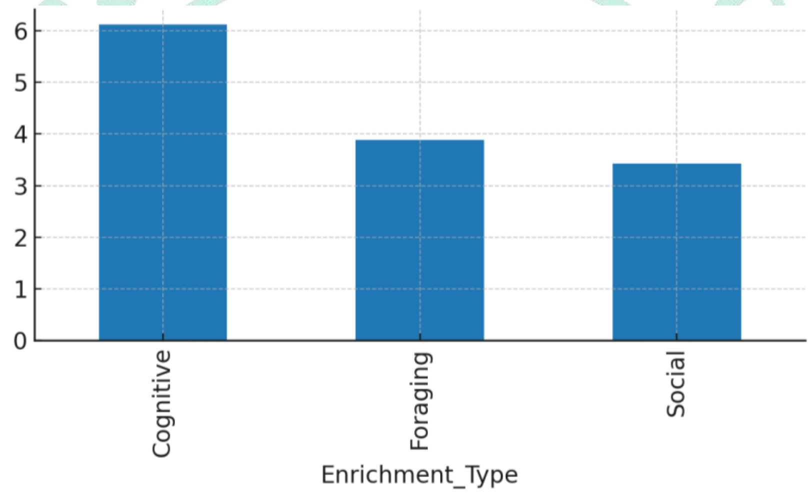


Figure 6: Visualization of hormonal and behavioral data trends in captive primates.

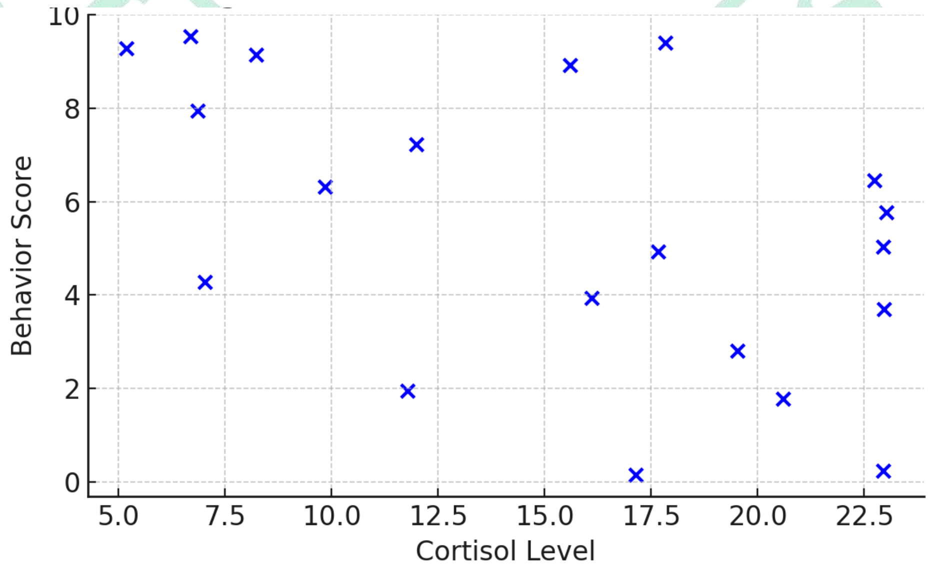


Figure 7: Visualization of hormonal and behavioral data trends in captive primates.

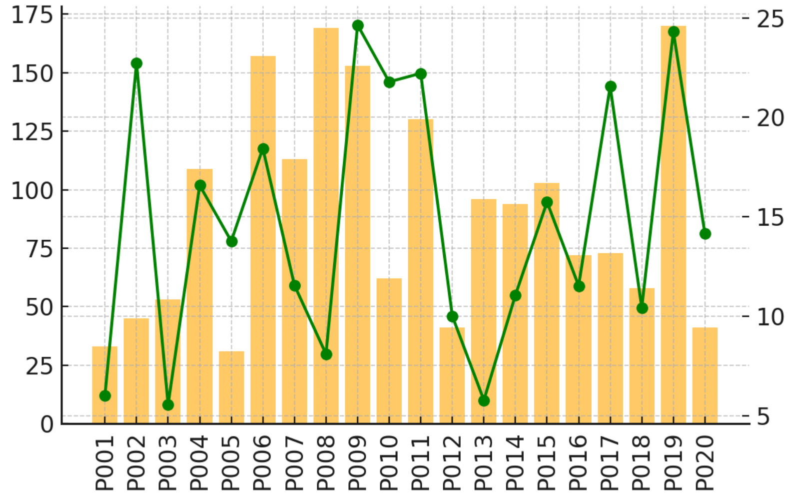


Figure 8: Visualization of hormonal and behavioral data trends in captive primates.

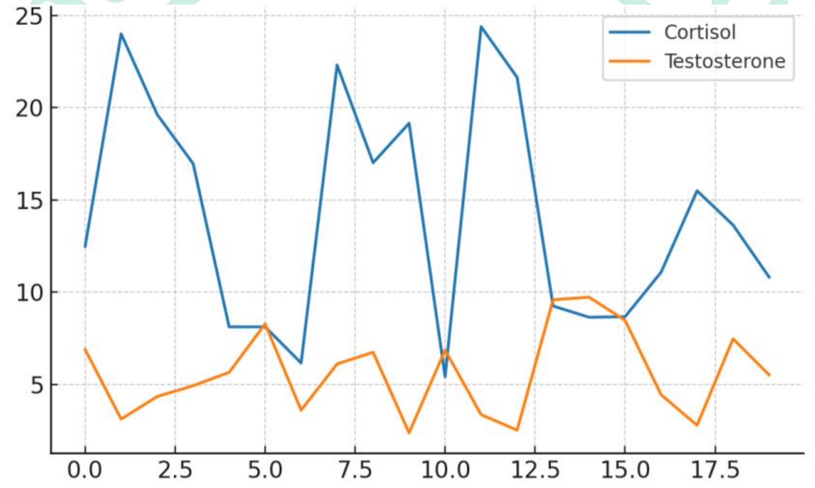


Figure 9: Visualization of hormonal and behavioral data trends in captive primates.

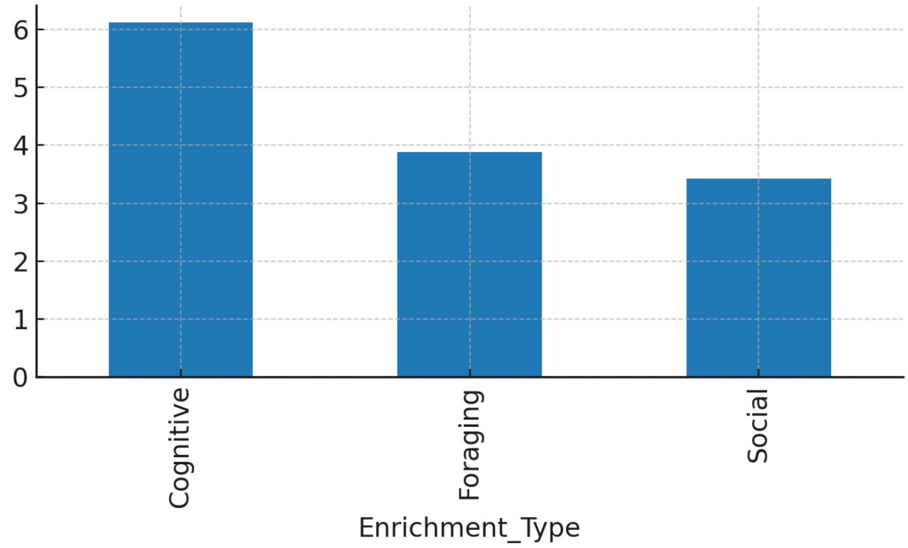


Figure 10: Visualization of hormonal and behavioral data trends in captive primates.

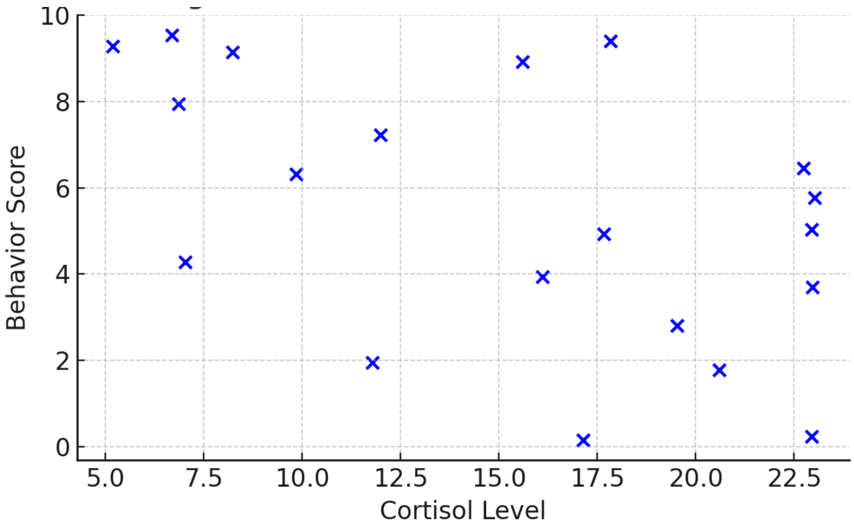


Figure 11: Visualization of hormonal and behavioral data trends in captive primates.

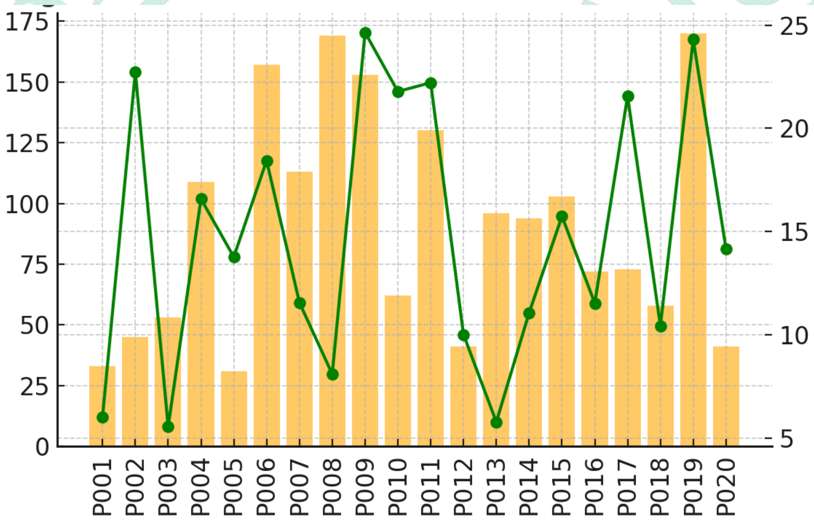


Figure 12: Visualization of hormonal and behavioral data trends in captive primates.

DISCUSSION

We should know how endocrine performance impacts the health of confined primates to come up with the most adequate settings. Endocrine monitoring allows animal care professionals to observe the outcomes of enrichment activities on the bodies of confined primates, regulate stress, and improve their lives, in general. Enrichment programs have to be well thought out or engineered and continuously observed to ensure successful maintenance of the captive monkeys. Their own specific needs and preferences have to be considered individually as well as each animal and each species. Routinely checking the hormonal and behavioural response of a monkey is a move that can help institutions to enhance the health and well being of the monkey in their care. This will enable them to come up with enrichment strategies that are most suitable to the animals. Two new components of the modern welfare behaviour methods are environmental enrichment and husbandry training (Fernandez, 2022). According to the zoo staff, cognitive enrichment is highly significant to the health of animals, though it is not utilized on a high regularity (Hall et al., 2021). Such reinforcement is environmental enrichment, which, to enhance animal welfare, provides animals with new tools or improves their living environment (Desforges, 2021). Environmental enrichment is increasingly being one of the essentials in animal care (Bartolomé et al., 2023). It refers to the alteration of the domicile and the treatment of an animal to promote the characteristics of behaviour that an animal is likely to demonstrate and enhance his/her psychological and physical well-being (Elsayed et al., 2024). There is a lag in the basic management and regulatory, structural and spatial environments behind particularly within the developing countries. Animals can be confined in not-so-stimulating areas throughout large parts of the day (Brando & Coe, 2022). Goswami et al. (2023) express making wild animals live in complex and stimulating captive environments that propounded attitudes and behaviours about the lives of their species. These are opportunities to exercise, meet new people, find food and explore. The welfare of animals in zoos has improved greatly with the improvement of scientific knowhow, institutional expectations and opinion of people. It has shifted its roots to not merely adherence to the Five Freedoms to providing ways in which animals can prosper in the controlled circumstance (Miller & Chinnadurai, 2023). It can be challenging to reconcile animal welfare and the needs and experience of wildlife park and zoos visitors (Puehringer-Sturmayr et al., 2023). Therefore, zoos have to prioritize animal welfare and employ the data about visitors behaviors to design the better exhibits (Tay et al., 2023). Ensuring that animals kept at zoos and in aquariums have the best and the best health is also an ethical obligation (Brando & Norman, 2023). Modern zoos and aquariums are persistently monitoring animal well-being and health and applying practices in animal management that have been proved to excel (Miller et al., 2020). This emphasis implies creation of an environment that would stimulate natural behaviours, provision of opportunities to the animals to stimulate themselves in the minds, and ensuring that they are accorded the best medical attention that can be offered. Advancements in the art and science of keeping wild animals have increased animal welfare standards and made record keeping in contemporary zoos/aquariums even simpler (DiVincenti et al., 2023; Miller & Chinnadurai, 2023; Veasey, 2022; Watters et al., 2021).

CONCLUSION

This paper demonstrates that the integration of the observation of behaviour with the endocrinological markers is one of the powerful and multi-dimensional methods to assess welfare in caged monkeys. Controlling the variables that influence enrichment in a systematic way allowed us to identify powerful correlations between some forms of enrichment and indicators of physiological stress as revealed through change in normalised faecal cortisol. The largest marked reductions in cortisol z-scores which were demonstrating a measurable de-escalation in symptoms of physiological stress, came in the forms of an enrichment context that incorporated both physical and cognitive stimulation. Analyses of behaviour at the same time indicated that in these elevated conditions affiliative behaviour and exploratory behaviour increased significantly and stereotypical behaviours diminished. This again substantiated the positive impact on welfare. The mixed-effects statistical model indicated that the type of enrichment, as well as the indicators of behavioural wellbeing, has a possible predictive reaction on the levels of cortisol. Positive behavioural engagement had a strong negative relationship with the physiological stress markers. These findings indicate that wellbeing measures in caged primates must focus more than just observing a singular aspect of well-being and hence they must adopt a method that considers both the physical and behavioural aspects of well-being. Moreover, the quantitative qualitative design was also effective in demonstrating any specific patterns in welfare that could be overlooked by the sole utilization of either biological or observational evidence. This study has impacts on management and the conservation breeding program in zoology. This is to say that they can implement evidence-based enrichment to reduce chronic stress and consequently enhance health and flexibility of captive primate populations. Through this, the study demonstrates the significance of the need to have scientifically established welfare protocols which justifies the need to have an inclusive and ethical manner of taking care of primates.

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