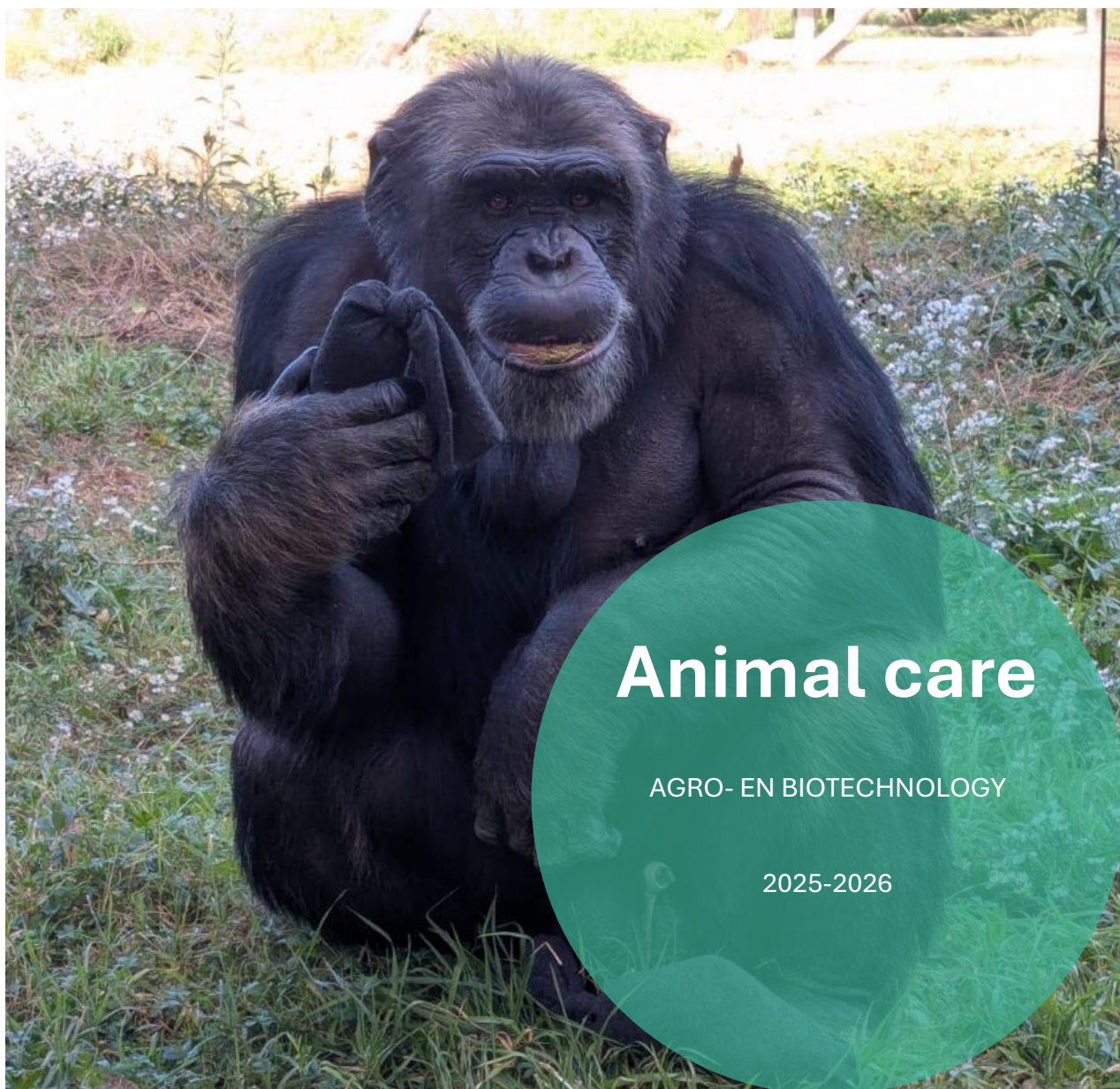




Animal care

AGRO- EN BIOTECHNOLOGY

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Responses to rosemary-based olfactory enrichment

A behavioural analysis of captive chimpanzees (*Pan troglodytes*) at Fundació MONA

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Preface

During the COVID-19 pandemic, I realised that I wanted to make a career change to pursue a path working with animals. This led me to start the Bachelor programme in Agro- and Biotechnology, specialising in Animal Care. During my studies, I was given the opportunity to work with wildlife, and particularly primates, in Peru and Indonesia.

Discovering Fundació Mona in Girona made it clear to me that conducting a small-scale study on olfactory enrichment in captive chimpanzees could be a realistic and valuable project for my bachelor thesis. I decided to take on this challenge, and it turned out to be an incredibly rewarding experience. I learned a great deal about chimpanzee behaviour, social interactions, and observational methodologies.

I am deeply grateful to research project coordinator Dietmar Crailsheim and co-promotor Hilde Vervaecke for their continuous support and guidance throughout this process, even after I returned to Belgium to complete the writing of this thesis.

Returning to a bachelor's education after 15 years of working was one of the best decisions I have ever made. Although it was not always easy, it was always worthwhile. I am proud of the work presented in this thesis and hope it may contribute to future research on olfactory enrichment for chimpanzees and other captive primates.

Finally, I would like to thank my parents for their unwavering support, which made it possible for me to take this step and return to studying. The friends that helped me shape, proofread and finalize this thesis will have my never-ending gratitude. I am also grateful for the friends I made during this programme — their encouragement, advice, and companionship made this journey just as meaningful as its destination.

Summary

Environmental enrichment is a key component of welfare management in captive primates, particularly in rescue and sanctuary settings where individuals often originate from deprived backgrounds. While enrichment research has traditionally focused on cognitive, physical, and feeding-based interventions, olfactory enrichment remains relatively understudied in great apes.

This study investigated behavioural responses to rosemary-based olfactory enrichment in captive chimpanzees (*Pan troglodytes*) at Fundació MONA (Spain). Enrichment consisted of cotton socks infused with dried rosemary and was compared across three conditions: scented socks (“romero”), unscented control socks (“empty”), and a baseline condition without socks (“nothing”). Behavioural data were collected over four weeks using scan sampling combined with instantaneous and continuous recording, and activity budgets were analysed using linear mixed-effects models, accounting for repeated measures at the individual level.

Chimpanzees showed a clear preference for rosemary-scented enrichment, interacting more frequently with scented socks and spending a greater proportion of time in contact with them compared to controls. Exposure to rosemary was associated with a significant reduction in stress-related behaviour and a significant increase in foraging behaviour relative to baseline conditions. These effects were not observed in the control condition, indicating that behavioural changes were driven by olfactory properties rather than object presence. No significant effects of sex or group were detected.

Limitations include observer bias, a small sample size, the use of a single sanctuary population, a single olfactory stimulus, and a relatively short observation period.

Overall, the results indicate that rosemary-based olfactory enrichment can positively influence specific behavioural domains in captive chimpanzees. As a minimally invasive and easily implemented strategy, olfactory enrichment represents a valuable addition to welfare programmes in sanctuary and rehabilitation settings.

Samenvatting

Omgevingsverrijking vormt een essentieel onderdeel van het welzijnsmanagement bij primaten in gevangenschap, in het bijzonder in opvang- en rehabilitatiecentra waar dieren vaak afkomstig zijn uit sociaal en ecologisch verarmde omstandigheden. Hoewel onderzoek naar verrijking zich traditioneel richt op cognitieve, fysieke en voedsel gerelateerde interventies, blijft de rol van olfactorische prikkels bij mensapen relatief onderbelicht.

In deze studie werd het gedrag van chimpansees (*Pan troglodytes*) onderzocht in reactie op olfactorische verrijking met rozemarijn in Fundació MONA (Spanje). De verrijking bestond uit katoenen sokken gevuld met rozemarijn en werd geëvalueerd in drie experimentele condities: geurende sokken ("romero"), controle sokken zonder geur ("empty") en een baselineconditie zonder sokken en zonder geuren ("nothing"). Gedragsgegevens werden gedurende vier weken verzameld aan de hand van scan sampling gecombineerd met continue en momentane observatiemethoden en geanalyseerd met lineaire mixed-effects modellen, waarbij rekening werd gehouden met herhaalde metingen per individu.

De chimpansees vertoonden een duidelijke voorkeur voor de geurende verrijkingsobjecten, met een hogere interactiefrequentie en een groter aandeel observatiemomenten met fysiek contact in vergelijking met de controleconditie. Blootstelling aan rozemarijn ging gepaard met een significante afname van stress gerelateerd gedrag en een toename van foerageergedrag ten opzichte van de baselineconditie. Deze effecten werden niet waargenomen bij de controleobjecten, wat erop wijst dat de gedragsveranderingen toe te schrijven zijn aan de olfactorische eigenschappen van de verrijking en niet louter aan de aanwezigheid van objecten. Er werden geen significante effecten van geslacht of groepssamenstelling vastgesteld.

Bij de interpretatie van de resultaten dient rekening te worden gehouden met enkele beperkingen, waaronder mogelijke observatorbias, een beperkte steekproefgrootte, het gebruik van één enkele populatie in één opvangcentrum en één type geurstimulus, evenals een relatief korte observatieperiode.

De resultaten wijzen erop dat olfactorische verrijking met rozemarijn een positieve invloed kan uitoefenen op specifieke gedragsdomeinen bij chimpansees in gevangenschap. Als eenvoudig toepasbare en weinig invasieve verrijkingsvorm kan het een waardevolle aanvulling vormen op bestaande welzijnsstrategieën binnen opvang- en rehabilitatiecontexten.

Responses to rosemary-based olfactory enrichment
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1. Introduction

Chimpanzees (*Pan troglodytes*) are a highly social primate species indigenous to central and western Africa (Aebischer et al., 2017). In their natural environment, they form complex social structures characterized by hierarchical group dynamics, typically comprising approximately 35 individuals, with leadership often vested in a dominant male. Chimpanzees exhibit a rich and diverse behavioural repertoire, including complex social interactions, tool use, exploration, and nest-building (Inoue & Shimada, 2020).

Despite their behavioural flexibility and cognitive complexity, wild chimpanzee populations are currently classified as endangered and face multiple severe threats to their survival (Humble et al., 2016). Major contributing factors include poaching for bushmeat, capture for the illegal pet trade, exploitation for entertainment purposes, and the ongoing destruction and fragmentation of natural habitats (Humble et al., 2016). As a consequence, many chimpanzees are rescued from inappropriate conditions as pets or as entertainers and housed in sanctuaries such as Fundació MONA.

In captive environments, chimpanzees are often exposed to conditions that differ substantially from those of their natural habitat. The relative lack of environmental complexity and sensory stimulation may result in reduced behavioural diversity and can contribute to boredom, stress, and the development of abnormal or stereotypic behaviours. In light of the conservation status of chimpanzees and the increasing number of individuals living under human care, environmental enrichment programmes have been developed with the aim of promoting species-typical behaviours and enhancing psychological well-being (Young, 2013; Angleley et al., 2024; Bernstein-Kurtycz et al., 2020; Birkett & Newton-Fisher, 2011; Brent, 1992; Csatádi et al., 2008; Padrell et al., 2021; Richardson, 2024; Pruetz & Bloomsmith, 1992).

Improving captive welfare through enrichment strategies has become a central focus in primate management and research (Young, 2013). Among the various enrichment strategies, olfactory enrichment has gained growing interest due to its potential to stimulate exploration, foraging, and behavioural engagement. These behaviours are considered important indicators of positive welfare states, as they reflect opportunities for animals to engage in rewarding, species-typical activities and experience positive affective states, as described within the Five Domains Model of animal welfare (Mellor, 2016).

1.1 Literature review

This literature review first explores the evolutionary significance and the general importance of the sense of smell, with particular attention to primates. It then examines the use of olfactory enrichment in captive settings, highlighting both its successes and limitations. The scarcity of research specifically of olfactory stimuli has provided the motivation for the present study. Finally, this chapter discusses the selection of rosemary (*Rosmarinus officinalis*) as a focal scent, considering its potential health-related and behavioural benefits, which make it a particularly promising candidate for olfactory enrichment.

1.1.1 Evolution of olfactory sense

Olfactory systems emerged early in vertebrate evolution, and their basic organization — olfactory receptors within a nasal epithelium connected to an olfactory bulb — has been conserved across diverse taxa (Shepherd, 2004). However, the degree of olfactory dependence varies widely. For example, canids, rodents, and many ungulates exhibit extensive olfactory receptors and have proportionally larger olfactory bulbs, enabling them to detect, process, and respond to a wider array of chemical signals, reflecting the importance of chemical communication and scent-based foraging in these species (Niimura, 2012). Birds, long assumed to have poor olfaction, are now known to use smell for orientation and food detection (Steiger et al., 2009). Among mammals, olfaction underlies crucial ecological functions such as mate choice, parental recognition, and territorial marking (Wyatt, 2014).

Comparative anatomical studies reveal that the relative size of the olfactory bulb and the number of functional olfactory receptor genes are associated with increased reliance on olfactory processing (Singletary & Hagerty, 2023).

Olfactory capabilities among primates vary along ecological and phylogenetic lines. Nocturnal species such as bushbabies and many lemurs exhibit pronounced olfactory adaptations, including a relatively larger olfactory bulb volume in proportion to total brain size (Barton et al., 1995). These strepsirrhine primates — lemurs and lorises — often rely on scent for primary communication and environmental exploration and make more frequent use of scent-marking than diurnal species (Laska et al., 2015; Scordato & Drea, 2007).

Old World primates, including chimpanzees and humans, show a reduction in olfactory receptor diversity relative to many other mammals, coinciding with the evolution of trichromatic vision (Gilad et al., 2004). Nonetheless, the olfactory bulb in great apes remains functional and better developed compared to that of humans, suggesting that smell continues to play a behavioural role even in visually oriented primates (Keller et al., 2007). This genetic differentiation highlights selective evolutionary pressures and ecological divergence in chemical cue processing (Kawamura & Melin, 2018).

1.1.2 Functional importance of sense of smell

Olfaction, or the sense of smell, is a versatile and evolutionarily ancient sensory modality that plays crucial roles in the behavioural ecology, communication, and physiology of animals (Hoover, 2010).

Olfaction is arguably most well-developed in rodents, canids, and some marsupials. Rodents, especially mice and rats, execute complex social and reproductive tasks through scent-marking and pheromonal communication, supporting cohort cohesion and reproductive suppression. Canids rely on odour for not only foraging but for sophisticated social messaging linked to hierarchy and territoriality (Mota-rojas et al., 2018).

Strepsirrhine primates, such as lemurs, are regarded as olfactory specialists within the primate order: their reliance on marking territory, signalling dominance, and guiding reproductive cycles through chemical cues is nearly unmatched. According to Elwell and Vaglio (2023) lemur species exhibit specialized scent glands and engage in behaviours such as wrist marking and social sniffing that are less frequent in anthropoids, like chimpanzees.

In chimpanzees, the significance of olfactory function has often been underestimated relative to vision and audition. However, accumulating evidence from comparative anatomical, genetic, and behavioural studies highlights olfaction as a core channel of ecological and social interaction (Go & Niimura, 2008).

Chimpanzees live in dynamic forest and savanna environments, where olfactory cues interact with fluctuating visual, auditory, and tactile information. Their capability to detect fruiting trees and evaluate food quality through scent supports foraging efficiency (Nevo & Heymann, 2015).

In the realm of social dynamics, olfaction offers a subtle way to convey information. Experiments by Henkel and Setchell (2018) in captive settings demonstrate that chimpanzees discriminate between odour samples from group members, kin, and non-group individuals. They spend more time investigating the scent of unfamiliar individuals, indicating that olfactory cues contribute to kin recognition, social affiliation, and detection of outsiders.

Chemical signalling further aids reproductive strategies. Although sexual swelling and visual cues dominate great apes mate choice, olfactory cues are likely used to assess reproductive state, especially oestrus, and minimize the risk of inbreeding (Elwell & Vaglio, 2023).

Chimpanzees occupy overlapping territories, and chemical cues play a subtle role in territory demarcation and intergroup boundaries. Scent-marking behaviours are more overt in some mammals—wolves, for example, use urine and glandular secretions to claim resources and signal group membership—but olfactory inspection remains critical for chimpanzees navigating home ranges and avoiding conflict with neighbouring groups. The ability to detect subtle social odorants despite the absence of scent-marking

behaviour suggests that olfactory processing still contributes to social regulation (Henkel & Setchell, 2018). Chimpanzees in the wild have been observed to sniff their environment and conspecifics in social and sexual contexts (Matsumoto-Oda et al., 2007). These findings challenge earlier assumptions of primate microsmaty and underscore the need to integrate olfaction into welfare and enrichment frameworks for captive apes.

Conclusively, chimpanzees and by association all great apes like bonobos, gorillas and orangutans embody a transitional olfactory strategy. While their ancestral ecology favoured chemical signalling, evolutionary pressures in dense, visually rich environments promoted the expansion of visual and cognitive skills, leading to a possible reduction in olfactory receptor gene repertoires (Kawamura & Melin, 2018). But rather than representing a diminished sense, olfaction in chimpanzees appears to operate alongside visual and cognitive modalities, forming an integrated sensory system. This more nuanced understanding suggests that olfactory cues remain ecologically and socially relevant for foraging, social regulation and environmental assessment, even in species where vision is highly developed (Barton, 2006).

1.1.3 The potential of olfactory enrichment

Environmental enrichment has been defined in multiple ways across the literature, but the underlying principle remains the same: it aims to improve animal welfare by enhancing psychological and physiological well-being in captivity (Clark & King, 2008). Shepherdson (1998), for example, described enrichment as “an animal behaviour 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.”

In primate welfare research, enrichment is commonly organized into five broad categories: social, physical, sensory, cognitive, and food-based (Buchanan-Smith, 2011; Young, 2013). These categories are not mutually exclusive, and some enrichment strategies may overlap across domains.

Sensory enrichment—stimulating visual, auditory, tactile, gustatory, or olfactory modalities—has become an important subset of this strategy and has been explored as a way to improve chimpanzee welfare, though results remain inconsistent (Young, 2013). For example, while early studies suggested calming effects of certain music genres, later research found little or no preference for music over silence and even reductions in social activity when music was imposed without choice (Howell et al., 2003; Wallace et al., 2017).

Similarly, olfactory enrichment aims to stimulate the sense of smell by introducing biologically relevant odours that can influence exploratory, affiliative, or stress-related behaviour (Vaglio et al., 2021). Although using scents or herbs has shown potential, its effectiveness depends on species-specific responses, environmental context, and the degree of control animals have over the stimuli (Wells et al., 2007).

A growing body of research demonstrates the potential of scent-based enrichment across diverse species. In carnivores, peppermint, catnip, and prey odours have increased activity and exploratory behaviour for example, in lions (*Panthera leo*) and cheetahs (*Acinonyx jubatus*) (Powell, 1995; Quirke & O’Riordan, 2011). According to LaDue and Schulte (2021), elephants respond to biologically relevant pheromones with changes in behavioural diversity and social interaction. Similarly, rodents and domestic dogs show both stimulating and calming responses depending on the chemical composition of the odour, with lavender often producing relaxation and peppermint or rosemary increasing locomotion (Rooney et al., 2023; Shaw et al., 2007). Within primates, the impact of olfactory enrichment is variable, reflecting differences in species’ olfactory sensitivity and behavioural ecology. Early studies with chimpanzees found limited behavioural effects when pleasant or unpleasant odours were applied to fleece cloths (Ostrower & Brent, 2000). However, other experiments involving diffused peppermint indicated increased activity levels, suggesting that mode of delivery influences outcomes (Struthers & Campbell, 1996).

Comparable results have been reported in other primates. In western lowland gorillas (*Gorilla gorilla gorilla*), odour-impregnated cloths elicited only brief sniffing responses without significant changes in overall activity budgets (Wells et al., 2007). Similarly, meerkats and ring-tailed lemurs showed non-significant or transient behavioural effects when exposed to lavender, rosemary, or coconut scents (Baker et al., 2018; Myles & Montrose, 2015). Yet more recent studies using concentrated or biologically relevant scents reveal clearer responses. Black-capped capuchins and common marmosets displayed distinct behavioural changes—such as reduced inactivity and increased exploration—when exposed to rosemary, banana essence, or deer urine (Wowk et al., 2023).

In mixed-species studies across lemurs, gibbons, howler monkeys and orangutans, essential oils like benzoin, lemongrass, and lavender modulated both behaviour and physiology, with some species showing reduced stress-related behaviours but elevated glucocorticoids (Gronqvist et al., 2013). These results emphasize that olfactory enrichment effects are species-dependent and can vary even within primate taxa.

Furthermore, the ecological relevance of the odour—whether it resembles a natural food, social cue, or environmental signal—affects how strongly animals respond (Quirke & O’Riordan, 2011). The finding by Freymann and others (2025) that chimpanzees in the wild self-medicate with plants and shrubs they come across or seek out, suggests they may selectively prefer certain plants with healing properties when in need. The delivery method also matters: diffused odours may create a more naturalistic and wide-spread sensory environment compared to localized scent patches (Struthers & Campbell, 1996).

Understanding olfactory ecology has applied benefits for conservation and captive welfare. Enrichment strategies in zoos and sanctuaries increasingly incorporate olfactory stimuli—essential oils, plant scents, food odours—to promote behavioural diversity and psychological well-being in chimpanzees (Elwell & Vaglio, 2023).

1.1.4 The nature of rosemary

Rosemary (*Rosmarinus officinalis*) is an aromatic, evergreen woody shrub native to the Mediterranean basin but now cultivated worldwide for culinary, ornamental, and therapeutic purposes. Renowned for its distinct fragrance, rosemary is rich in diverse bioactive compounds that underpin its longstanding use in traditional medicine and its growing role in evidence-based health interventions for both humans and animals (Ghasemzadeh Rahbardar et al., 2020).

Rosemary, peppermint, and catnip all belong to the botanical family Lamiaceae, commonly known as the mint family, which is recognized for its aromatic members and distinct botanical features such as square stems and opposite leaves (Rose et al., 2022). Despite differences at the genus level—rosemary within *Rosmarinus*, peppermint within *Mentha*, and catnip in *Nepeta*—they share key traits and chemistry due to their close evolutionary relationship (Uikey, 2024).

Lamiaceae family and chimpanzee ecology

The family is believed to have originated in the Old World, with centres of diversity in Eurasia, Africa, and the Mediterranean region (Uikey, 2024). The closest herb to *Rosmarinus officinalis* likely to be found growing in chimpanzee habitats in Africa is *Ocimum gratissimum*, also known as African basil or wild basil. This plant is a fellow Lamiaceae member, shares many aromatic compounds with rosemary, and is native to or widely naturalized in sub-Saharan Africa, including regions where chimpanzees live (Inegbedion, 2022). This species possesses aromatic oils rich in eugenol, thymol, and also contains various monoterpenes and sesquiterpenes similar to those in rosemary (Freymann et al., 2024). Ethnobotanical and primate behavioural studies confirm that *Ocimum gratissimum* is both used medicinally by local people and, in some regions, accessed or utilized by chimpanzees for its aroma and possible medicinal effects (Inegbedion, 2022; Uikey, 2024).

Chimpanzees living in the wild exhibit a well-documented capacity for self-medication, seeking out medicinal plants to treat health issues. While rosemary is not native to chimpanzee habitats, these apes are known to select leaves and stems of various plants for their bioactive, typically antimicrobial or anti-inflammatory, effects, either ingesting or applying them to wounds (Krief et al., 2006). Scientific investigations in Ugandan forests have catalogued a wide range of plant species used by chimpanzees in ‘forest first aid’ practices, including species with documented pharmacological properties overlapping those of rosemary (Freymann et al., 2025). Extracts of these plants frequently demonstrate anti-inflammatory and antibacterial activity when tested pharmacologically, confirming their functional value in ape health.

A list of all the interesting active ingredients of rosemary, like flavonoids or phenolic diterpenes and acids, is beyond the scope of this study; however, rosemary contains a blend of plant chemicals, known as active ingredients, that work together to protect the plant from pests and environmental stress, and these same chemicals can benefit human and animal health (Aziz et al., 2021).

1.1.4.1 Medicinal and health benefits for humans and animals

Regular dietary consumption of rosemary infusion has been shown to improve the body's antioxidative defence and reduce markers of inflammation. Rodent and human studies demonstrate decreased lipid peroxidation and normalized blood lipid profiles following rosemary tea intake, indicating that it helps moderate the cumulative impacts of cellular stress and metabolic disruption (Ghasemzadeh Rahbardar et al., 2020).

Traditional medicine has long advocated rosemary for headaches, emotional distress, and memory enhancement, and modern studies substantiate these claims via neuropharmacology. Regular intake of rosemary—whether through leaves or tea—can lower anxiety, improve mood, and enhance sleep quality in clinical and preclinical experiments (Ghasemzadeh Rahbardar et al., 2020). In hypertensive humans, rosemary infusions have also been linked to blood pressure reduction and improved daytime energy (Sassi et al., 2025).

Furthermore, regular ingestion of rosemary infusions supports the immune system's response to infection, as both in vitro and in vivo studies confirm broad-spectrum antibacterial, antiviral, and antifungal effects (Nieto et al., 2018).

Finally, clinical and animal studies suggest that rosemary can ameliorate hyperglycaemia, improve insulin sensitivity, and reduce dyslipidaemia, providing a rationale for its adjunctive use in metabolic syndrome prevention (Labban et al., 2014). It is important to note that most reported benefits here are derived from culinary or infusion doses and long-standing traditional use and not from essential oil usage.

Knowing that chimpanzees have self-medicated for parasitosis and related illnesses (Huffman, 1997), and bonobos (*Pan paniscus*) and gorillas (*Gorilla gorilla*) are known to consume the same parts of medicinal-plant species that humans do (Cousins, 2002), it may be hypothesised that some of the benefits observed in humans could also be relevant for chimpanzees, although direct empirical evidence remains limited. Cousins (2006) gives an overview of several herbs being used on primates for medication with the information we have for humans.

So rosemary leaves or infusions could offer:

- Enhanced antioxidant and anti-inflammatory protection, potentially reducing risks of chronic disease and infection, observed through studies with mammals and poultry (Nieto et al., 2018).
- Support for stress regulation and cognitive function, through behavioural enrichment and direct pharmacological modulation of neurotransmitter systems, evidenced by a large number of studies on animal models (Ghasemzadeh Rahbardar et al., 2020).
- Promotion of gut and systemic health due to antimicrobial action, possibly lowering pathogen load and supporting gastrointestinal wellness, through a field study on chimpanzees (Freyman et al., 2025).
- Increased locomotion through a higher alertness which is supported by mice and people experiments (Kovar et al. 1987; Diego et al., 1998)

- Anxiolytic-like behaviour in mice when consumption of rosemary infusion happens on a regular basis (Ferlemi et al. 2015).

Unlike volatile essential oils, whole-leaf rosemary and water-based extracts do not present the skin toxicity or ingestion risks associated with oils, making them safer for enrichment or even as a dietary option for primates.

1.2 Objectives

The primary objective of this study is to examine whether chimpanzees housed at Fundació MONA respond behaviourally to olfactory enrichment using rosemary. Specifically, the study aims to determine whether exposure to the scent of rosemary elicits observable behavioural changes.

Additionally, the study will consider potential differences between males and females in their responses to rosemary enrichment. It will also investigate whether chimpanzees that actively engage with the rosemary-scented enrichment items exhibit greater behavioural changes than the individuals that show little or no interest.

1.3 Hypotheses and research questions

Hypotheses

- Given its strong and distinctive odour, rosemary is expected to attract the chimpanzees' attention, leading to more interaction with the scented socks compared to the unscented socks.
- Chimpanzees that remain in active or passive contact with or interact with the scented items are expected to display behavioural shifts such as increased foraging, and/or affiliative social behaviours, and/or less inactivity and/or a reduction in stress-related behaviours.
- This final hypothesis is grounded in previous experiments conducted at MONA, where female chimpanzees participated significantly more than males ($p < 0.05$) (Padrell et al., 2022), as well as in earlier studies, such as Bernstein-Kurtycz et al. (2020), who reported that the youngest and most subordinate female primate within a group was the most successful in utilizing novel tool-based enrichment. More broadly, contemporary literature indicates that age and sex both independently and interactively shape primate engagement with enrichment, with younger and female individuals often showing higher levels of participation and innovation (Box et al., 1995; Eskelinen et al., 2015; Lonsdorf et al., 2004; Yamanashi et al., 2014). Based on this evidence, we predict that female chimpanzees in our experiment will interact more frequently with the scented socks.

Research questions

1. How do captive chimpanzees at Fundació MONA respond to the scent of rosemary?

- I. Do the chimpanzees interact with rosemary-scented socks when these are provided as enrichment?
 - II. How does this compare to the interaction with unscented (control) socks?
 - III. Are there sex-based differences in the level of interaction (number of times of interaction or total percentage of intervals spent) with rosemary-scented enrichment?
2. Does exposure to rosemary alter the chimpanzees' activity budgets, particularly in relation to foraging, affiliative behaviours, inactivity and stress-related behaviours?

2. Material and methods

2.1 Research setting: Fundació MONA

This observational study took place at Fundació MONA, a primate rescue and rehabilitation centre located near Girona, Spain. The sanctuary provides long-term care for chimpanzees and Barbary macaques (*Macaca sylvanus*) rescued from the pet trade, circuses, or the entertainment industry. At the time of this study, the chimpanzees lived in three social groups, Mutamba, Bilinga and a third group, Sugus, that was residing in a smaller enclosure prior to moving to a newly built larger enclosure.

The focus of our study will therefore be the groups Mutamba and Bilinga. They live in large, semi-natural enclosures designed to promote natural behaviour and social interaction. Each outdoor enclosure includes climbing constructions, bushes and other vegetation, tires, hammocks, connecting ropes and shelters. Mutamba's enclosure is labelled Enclosure 1 (2420m²) and Bilinga's enclosure is labelled Enclosure 2 (3220m²) (Chen *et al.*, 2025). The chimpanzees spend their days outdoors, with access to indoor facilities at night. For safety, the area is enclosed with electrified wires, which are checked every day, and a wall of vegetation is in place to ensure the animals' privacy, except for a few designated view- and observation points.



PHOTO 1. Enclosure 1, from visitors viewpoint. © Ann Ieven



PHOTO 2. Enclosure 1, from observation tower. On the right is the visitors viewpoint. © Ann Ieven



PHOTO 3. Enclosure 1, from observation tower. In the back Enclosure 2, with an electric fence in between. © Ann Ieven

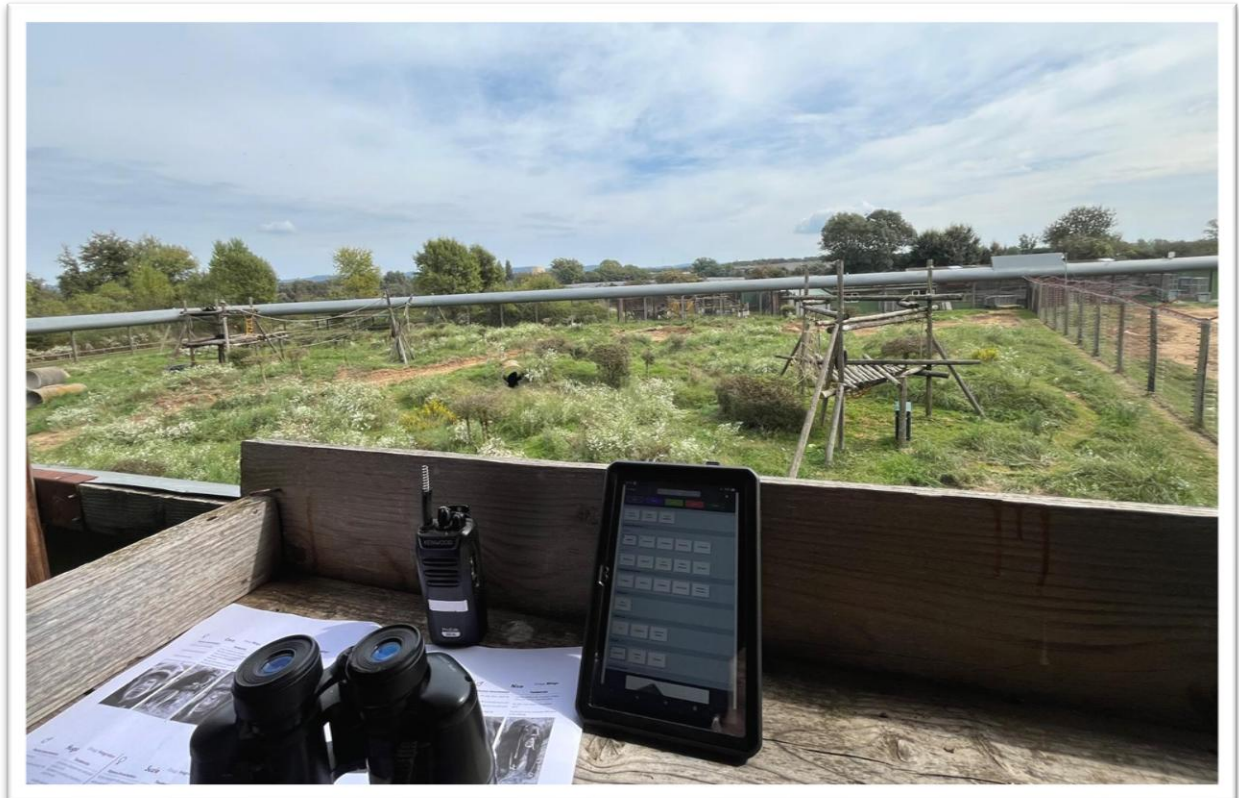


PHOTO 4. Enclosure 2, from observation tower, including the observation material (iPad with ZooMonitor, binoculars, identification sheet and walkie talkie). © Ann Ieven



PHOTO 5. Enclosure 2. © Ann Ieven



PHOTO 6. This map of the two outdoor enclosures shows both groups, Mutamba and Bilinga, separated by an electric fence. Not all buildings in this photo were still present at the time of the observations. © Ann Ieven, adapted from satellite imagery (Google Earth) of Fundació MONA enclosures.

2.2 Study population: group composition

The study population consisted of 10 adult chimpanzees housed at Fundació MONA during the study period (October–November 2025). The individuals were living in two stable social groups, Bilinga and Mutamba, each composed of both males and females of varying ages and social ranks.

Bilinga consists of 2 female chimpanzees Coco and Cheeta and 3 males Nico, Tom and Victor. There are also 3 males, Bongo, Marco and Juanito and 2 females, Waty and Africa, in Mutamba. They are all of adult age and come from a history of circus, pets or entertainment industry and have sometimes lived solitary for years.

During the data collection phase (in 2025), the chimpanzees' age ranged from 22 to 43 and their age at rescue from 1 to 29. With a mean age in Mutamba in 2025 of 28,4 years and in Bilinga of 35,4 years.

Group	Chimpanzee name	Sex	Origin	Estimated year of birth (age in 2026)	Age at rescue	Years at MONA (in 2026)	Early history	Social condition before rescue
Mutamba	Waty	Female	Captive	1997 (29)	5	24	Entertainment	Social
	Africa	Female	Wild	1999 (27)	10	17	Pet	Single
	Marco	Male	Captive	1984 (42)	17	25	Entertainment	Social
	Bongo	Male	Captive	2000 (26)	2	24	Entertainment	Social
	Juanito	Male	Captive	2003 (23)	1	22	Pet	Social
Bilinga	Cheeta	Female	Wild	1986 (40)	29	11	Entertainment	Single
	Coco	Female	Wild	1994 (32)	18	14	Pet	Single
	Victor	Male	Captive	1982 (44)	24	20	Pet	Single
	Tom	Male	Wild	1985 (41)	26	15	Entertainment	Social
	Nico	Male	Captive	2001 (25)	3	22	Pet	Single

TABLE 1. Summary of the main information available for each chimpanzee in our study groups, comprising its group at MONA, its sex, age and the info about the individual's previous (living) conditions, at time of publication.

Note:

“Origin” indicates if the chimpanzee was born in the wild or in captivity. We calculated the “Age at rescue” based on the year of arrival at MONA and the estimated year of birth. The “Years at MONA (in 2026)” refer to how long the animals have been at the sanctuary in 2026. “Early history” refers to the chimpanzee's commercial or private use before its arrival at MONA, best determined from available records. We categorized the subjects as “entertainment” if they had been primarily involved with circuses and/or commercial agencies; and “pet” if they had been kept in human households for exclusively private purposes. The “Social condition before rescue” refer to the chimpanzees' primary housing conditions, i.e., isolated or socially housed with conspecifics (Chen et al., 2025).

In Appendix 1 an photographic overview of all the observed chimpanzees, when possible with sock enrichment, is found.

2.3 Preparation and schedule of olfactory enrichment

In this experiment, enrichment consisted of cotton socks filled with dried rosemary. A total of 140 new socks were purchased, washed 2 times without fabric softener and prepared with mouth mask and gloves by the same person each time.

The socks that were used as “scented socks” were infused with rosemary water that was made of 60 grams of bruised and dried rosemary leaves per liter of boiling water, infusing for 10 to 15 minutes and then removing the rosemary leaves and cooling it down before soaking socks for 24 hours. Then the socks were dried outside before placing them in a sealed plastic bag until used, not more than 3 days later.

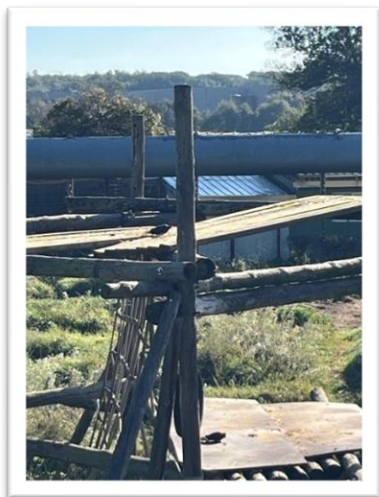
The afternoon before the morning of use, the scented socks were filled with at least 40 grams of rosemary, consisting of 20 grams of the leaves that had been used for the infused water and 20 grams of bruised dried rosemary leaves, together with a handful of straw to make the sock into a lightweight, visible (from the observation tower) object. They were then placed in a sealed bag and the name of the group and content of the socks was written on a sticker on the bag.

To evaluate the specific effect of scent, unscented socks filled only with straw served as a control sample (“empty”). All the other days were normal, baseline days (“nothing”) were other enrichment was given according to the schedule of MONA, but no socks and no scents were added.

In appendix 2 a photographic overview of the techniques used is found.

2.4 Behavioural observation: design and measurement methods

We collected behavioural data over four consecutive weeks, starting Monday November 3rd 2025 until Monday December 1st 2025. The socks (scented or unscented) were placed in the enclosure in the morning, before the chimpanzees went out and were available throughout the daytime (approximately from 10:00 AM to 5:00 PM).



Depending on the weather the hours outside would vary a bit, going outside half hour later or letting them back inside sooner when it was really cold or windy, or leaving them out a bit later when it was nice and sunny. Some days groups were switched between enclosures, normally Mutamba is in Enclosure 1, next door is Bilinga in Enclosure 2 and Sugus in the smaller, outside enclosure on the other side of a building. When Bilinga and Mutamba were not in their normal enclosures or their neighbours were not their usual neighbours, there were no observations. Caregivers decided on who stayed where daily and the observations adapted to their schedule. No changes were made to their schedule for the experiment.

PHOTO 8: Socks in enclosure 2 in the morning before the chimpanzees come out. © Ann Ieven

Observations were then carried out twice daily for 6 consecutive sessions of 20 minutes between 10:00 AM (or when the chimpanzees would come outside) to 4 PM, giving a total of 4

hours of observation time per day per enclosure. The observers were stationed on one of the two observation towers to oversee the respective enclosure.

In each week there was 1 scented-sock-day and 1 unscented-sock-day; the other days were normal (baseline) days. Through randomisation the scented and unscented socks were spread over the weekdays, when conditions explained above were met. The general enrichment program was continued during the experiment and the socks were an additional item to be discovered in the enclosures. The normal program of enrichment is detailed below:

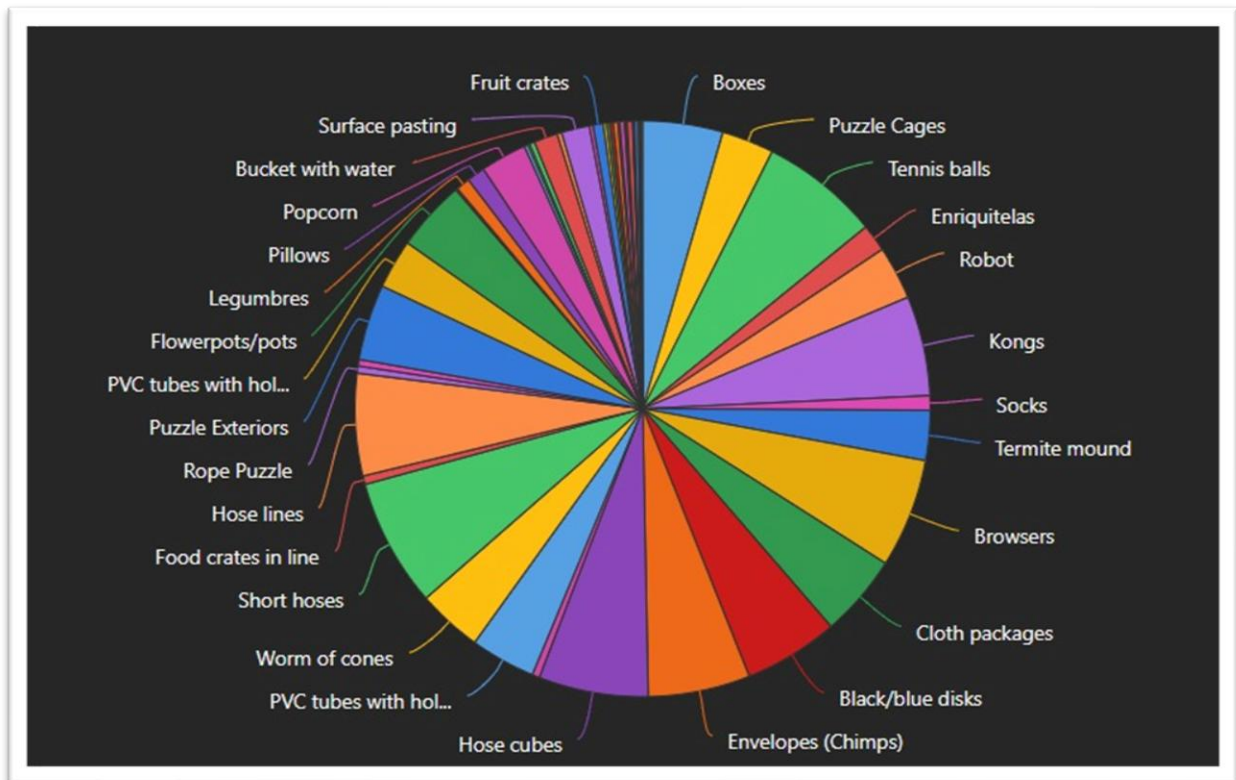


PHOTO 7: Overview of all enrichments used during observation period © Fundació MONA (used with permission).

In appendix 3 is the daily program of the enrichment during the four weeks of observations.

Both the author and other observers at the sanctuary received training from the research coordinator at MONA and were assessed as official observers after passing a three-step quality and interobserver reliability test with an agreement rate exceeding 85% with the research staff at MONA. All the data were collected using ZooMonitor data scoring software, an application which facilitates the recording and analysis of animal behaviour (Wark et al., 2019).

Introduction to sampling and recording methods

In behavioural research, the design of an observation protocol is based on two key methodological decisions: sampling and recording (Altmann, 1974). Sampling refers to the rules governing *who is observed and when observations occur*, whereas recording refers to the rules specifying *how behavioural data are documented and recorded during those observations*.

When the aim is to obtain detailed behavioural data from a single individual, researchers typically use focal animal sampling, in which one subject is observed continuously over a predefined period and all behaviours are recorded during that time. In contrast, scan sampling involves observing behaviour at predetermined time points and is often done across an entire group. The behaviour of each visible individual is recorded at each sampling instant.

Concerning the recording methods, in instantaneous recording, behaviour is recorded at fixed time points (e.g. every 2 minutes), and only the behaviour occurring at that exact moment is noted. In continuous recording, all occurrences of the selected behaviours are recorded as they occur, including their onset and offset, allowing for precise measurement of duration and sequence (Altmann, 1974).

Sampling and recording methods used for this experiment

Behavioural data were collected using scan sampling at 2-minute intervals (Altmann, 1974), with behaviour recorded at each sampling point for all visible individuals, including solitary and interactive behaviour, social proximity, object use, and vertical position.

In addition, continuous recording and event sampling was used to record all occurrences of newly initiated behaviours such as direct interactions with the socks by any of the group members. A new event was logged each time an individual released and then re-engaged with a sock. This sampling method is also standard for MONA's protocol.



PHOTO 9: Observer. © Ann Ieven

2.5 Ethogram and behavioural categories

The screenshot displays the ZooMonitor application interface, which is organized into several horizontal sections, each representing a different category of behavior. Each section has a title and a subtitle indicating when to tap. The categories and their sub-items are as follows:

- All-Occurrence Behaviors** - Tap any time behavior occurs
 - Display undirected
 - Display directed
 - Physical aggression
 - Sock Interaction
- Solitary Behaviors** - Tap one at interval
 - SOLITARY1**
 - Inactivity
 - Alimentation
 - Locomotion
 - Manipulation
 - Self directed
 - SOLITARY2**
 - Solitary play
 - Abnormal
 - Other Individual
 - Human Interaction
 - Not visible
- Interactive Behaviors** - Tap one at interval
 - Grooming
 - Affiliative
 - Agonistic
 - Socio sexual
 - Interaction other group
- Proximity** - Tap one at interval
 - Social Proximity
- Object use** - Tap one at interval
 - Tool
 - Enrichment
 - Enrichment and tool
 - Sock
 - Sock + Enrichment
- Height** - Tap one at interval
 - ground level
 - Elevated level
 - Top level

Figure 1. Print screen of ZooMonitor screen during observations

The all-occurrence behaviours were recorded with a continuous scan method. The definitions are given in the table below.

ALL OCCURRENCE: Events		
Display undirected	Individual shows off strength, but towards no one in particular. May include vocalisations such as strong lip splutter, hooing, or hooting. Chimpanzee tends to be pilo erected, running, swaggering, stomping the ground, throwing objects or hitting elements or structures.	
Display directed	Individual shows off strength specifically towards a particular chimpanzee, animal or human, often while approaching said individual gradually. May include vocalisations such as strong lip splutter, hooing, or hooting. Chimpanzee tends to be pilo erected, running, swaggering, stomping the ground, throwing objects or hitting elements or structures.	Mark target individual(s) or Other group, Visitors, Observer, Staff.
Physical aggression	Chimpanzee directly attacks another chimpanzee entering in physical contact. This may include running over another chimpanzee, shoving, hitting, kicking or biting the other individual.	
Sock interaction	Chimpanzee is handling, sniffing, picking up the sock in a deliberate manner	

All the other behaviours were recorded using an instantaneous scan method with 2 minute intervals in 20 minute sessions. Per colour only one behaviour can be selected, unless it is a sub-behaviour. For example, if inactivity is selected, one of three sub-behaviours also need to be selected. The definitions are given in the tables below.

Interval: SOLITARY BEHAVIOR CHANNEL		
Inactivity	Resting	Stationary without actively interacting with himself, others or the environment.
	Vigilance	Fixed gaze at something or someone or scanning the distant environment. It includes looking at distant group members, other groups, and the surrounding area. Mark the target of the behaviour: Own group, Other group, Visitors, Observers, Head keeper, Caregiver, Office staff, Veterinarian, Technician, Mkks.
	Relaxed resting	Dozing or sleeping in an upward-facing or lateral position with either elongated or bent limbs (without hugging oneself). The individual does not show any indication of being focused on himself, any other individual or their general environment. The individual is not exhibiting RELAXED RESTING if he goes into a fetal position (may include hugging limbs and/or patting oneself with fingers on various parts of the body), nor any other behaviour categorized as abnormal, such as: self-poking or self-clasping, etc.
Alimentation	Feeding	Ingest or handle solid or liquid food in a stationary position.
	Foraging	Active search and/or transport of food (the animal keeps its eyes focused on possible food sources). It can include punctual food intake without interrupting gathering food.
	Food extraction	The chimpanzee is working an enrichment device/item (provided by care givers) which contains food items.
Locomotion		Displacement from a point A to a point B on a vertical or horizontal surface, while not exhibiting any other behaviour from the behavioural catalogue.
Manipulation		Inspecting elements of the environment or non-food enrichment with the upper or lower extremities. May include using the mouth, but not the mouth alone.

Self directed	Behaviours directed towards the individual (own body), such as self-cleaning (auto grooming), self-inspection, masturbation, scratching, scrubbing, body inspection, yawning or manipulation of specific body parts.	
Solitary play	Ludicrous behaviours exhibited while being alone. Has to be (at times) accompanied by either laughing vocalisations, a "play face", acrobatic body movements and/or galloping. May include the use of the environment or objects.	
Abnormal	Behaviours not typically seen in wild populations or normal behaviours exhibited in an excessive manner or as an inadequate, non-adaptive response to a specific situations:	
	Self scratch	Invariable, rhythmic and repetitive movement of the fingers or with an object (e.g. stick) rubbing some part of its own body.
	Self poke	Inserting, pressing or twisting of fingers or objects (e.g. sticks) repeatedly or continuously in a part of the body (only mark when actively manipulating or maintaining contact). Typically ears, nose, eye socket, armpit or anal area.
	Self clap	Hitting (soft or hard) a specific part of the body with hands or feet rhythmically and repetitively.
	Rocking	Repetitive and invariable swinging back and forth of the body while sitting (they can hug or grab objects at the same time, (e.g. pile of straw).
	Over grooming	Excessive self-cleaning behaviour of the skin / coat with hands or mouth, which may include pulling and ingesting hair. The behaviour can also be focused on wounds or damage to the skin, deteriorating its condition. They usually do it on the same areas of the body with a visible lack of hair.
	Coprophagy	Handling and/or ingesting of faeces (both own and others).
	Lip picking	Localized lip chewing with canine and/or manipulation with fingers. May lead to bleeding.
	Touch forehead	Prolonged touch or manipulation of forehead occipital bone (area around eyes).
	Other abnormal	Other abnormal or stereotypical behaviours not described above. The majority can be identified due to its rhythmically, repetitiveness and/or excessive frequency.
Other individual	Behaviours exhibited while being alone that are not better defined by any other category of the "Solitary Behaviour" group.	
Human interaction	Any behaviours directed or related to humans in proximity.	
	Human display	Chimpanzees show threatening behaviour and/or perform an agonistic display directed at humans in close proximity. It may include attempts to come into physical contact, throw items, or spit.
	Human submissive	Chimpanzees are agitated with a scared face can include behaviours such as asking for support, crying or yelling directed at a human.
	Human affiliative	Neutral or positive social interaction between the chimpanzee and a human. Includes calling the attention, greetings, as well as physical contact of non-agonistic nature. It can be initiated by animals or by humans.
	Human follow	Synchronized locomotion in parallel to the fence following the path that people take around the enclosure.
	Human observe close up	The individual remains less than 1.5 meters from the fence observing humans in close proximity without interacting in any way.

Mark the target of the behaviour:
Visitors,
Observers, Head keeper, Caregiver, Office staff, Veterinarian, Technician.

Not visible		There is no or insufficient information regarding the behaviour the animal is exhibiting:
	Not located	Observer does not know/see where the chimpanzee is.
	Interior	Chimpanzee has access to both indoor and outdoor enclosures and is located in the not observable indoor facility.
	Not present	The individual is not present, for example is inside with caregiver to get medical attention or just inside with no outside access

Interval: INTERACTIVE BEHAVIOR CHANNEL		
Grooming		Body-cleansing behaviour from one individual to another (includes mutual grooming), performed with the upper extremities or with the mouth.
Affiliative		This includes all socio-positive behaviours directed and/or received by another member of the same group.
	Social Play	Ludicrous behaviour between two or more individuals punctually accompanied by playful indicators (e.g., play face, laugh, gallop, cartwheels and pirouettes). Tag, catch and grab limbs or objects, tickles, muzzling, rough-and-tumble. These interactions do not require permanent physical contact.
	Follow	Synchronized movement of walking behind or beside another individual, following the trajectory of one or several chimpanzees (always mark mutual). Chimpanzee might touch in occasions, but might also maintain a big distance.
	Feed together	Two or more chimpanzee feed from the same food source or forage in close proximity, sharing/allowing the collection of food within their reach by another individual, sharing the food in a passive way (always mark mutual).
	Embrace	An individual hugs or tries to hug another with one or both arms in the absence of an agonistic event or agonistic indicators such as aggressive or submissive mimics. This behaviour can occur while stationary or while in movement.
	Other affiliative	Other affiliative-like behaviours that cannot be defined by any of the listed social behaviours.
Agonistic		This includes all aggressive or submissive behaviours directed and/or received by another member of the same group.
	Aggression	Behaviours relating to the agonistic/display threat, direct aggression, wounding, chasing, displacement and/or resource appropriation (including object and social resources). It can be accompanied by vocalizations. Chimpanzee is typically choosing more dominant and impressive body position to appear bigger and threatening. Movements are broad and often contain drumming, swaggering, stomping etc.
	Submission	Behaviours indicating fear or subordinate intentions toward one or several other chimpanzees. The chimpanzee shows signs of fear directed at another individual in an agonistic context. It may include approaching and presenting vulnerable body parts in an attempt to appease or avoid or flee from an individual displaying aggressive behaviour. It can include actions such as genital presenting, extending limbs, hand to mouth, running away, avoiding, and is typically accompanied by a scared face and vocalizations such as yelling, screaming, crying or pant-grunting.
	Other agonistic	Other aggression-related behaviours that cannot be defined by Aggression or Submission.
	Display undirected	Individual shows off strength, but towards no one in particular. May include vocalisations such as strong lip splutter, hooing, or hooting. Chimpanzee tends to be pilo erected, running, swaggering, stomping the ground, throwing objects or hitting elements or structures.

	Display other species	Individual shows off strength specifically towards an animal of a different species (e.g. Barbary macaques), often while approaching said animal(s) gradually. May include vocalisations such as strong lip splutter, hooing, or hooting. Chimpanzee tends to be pilo erected, running, swaggering, stomping the ground, throwing objects or hitting elements or structures.
	Socio sexual	Sexual interaction, or attempt of sexual interaction, between two individuals. Includes behaviours such as: copulation, attempted copulation, genital presentation, genital inspection and other behaviours directed towards the genital area of another individual. Choose between Genital inspection or copulation. In the latter the male chimpanzee would mount, including thrust movements, the female at one point (the mounting might only last a few seconds).
	Interaction other group	Any social interactions directed and/or received by members of a neighbouring chimpanzee group. Social sub behaviours (i.e., Aggression, Display, Submission, Social play, Follow, Other affiliative, Other agonistic) are defined identically as in in-group interactions. Here Directionality has to be marked within the observed chimpanzee.

Interval: PROXIMITY CHANNEL	
Social proximity	This is not a behaviour. Sharing a space during inactivity, or associated with other individual behaviours, while the distance between individuals is less than the length of the upper extremity (includes physical contact). Social Proximity is only recorded between animals that do not interact socially at that time.

Interval: OBJECT USE CHANNEL	
Tool	Chimpanzee is using an element as an instrument. Using a mobile element, external to the body, to perform a directed action on another object, surface or body. Is marked in combination with a behaviour.
Enrichment	Chimpanzee is using or is in contact with an enrichment provided by care staff. (Bedding material such as straw does not count as enrichment). Is marked in combination with a behaviour.
Enrichment and tool	Chimpanzee uses a tool to manipulate an enrichment provided by care staff. Is marked in combination with a behaviour (typically in combination with Food extraction).
Sock	Chimpanzee is in physical contact with the sock (can be active or passive)
Sock + Enrichment	Chimpanzee is in physical contact with the sock (can be active or passive) while also using or in contact with enrichment provided by care staff.

Interval: HEIGHT CHANNEL*	
Ground level	Chimpanzee is located on the ground or an elevation that does not require climbing to reach.
Elevated level	Chimpanzee is located on a structure that required climbing, yet is not located on the highest possible spot.
Top level	Chimpanzee is located on the highest part of a structure (post top or highest platform).

* height levels are specified for each structure separately.

2.6 Data recording and analysis

Data were recorded manually through ZooMonitor and later transferred into Microsoft Excel for analysis (Lincoln Park Zoo, 2022).

Each individual had a separate dataset comprising scan counts for each behavioural category under three experimental conditions:

- (1) rosemary-scented socks (“romero”),
- (2) unscented (control) socks (“empty”), and
- (3) no scented enrichment (baseline) (“nothing”).

Activity budgets were calculated as percentages of total observation time per category.

During the four week observation period we had 4h per observation day, 4 days or 16 hours for every condition, so 12 days or 48 hours of total observation time.

Statistical analyses were conducted in RStudio version 2025.09.2 Build 418 using R (R Core Team, 2025). Linear mixed-effects models (LMMs) were fitted using the lme4 package (Bates et al., 2015). LMMs were used because behavioural responses were expressed as continuous proportions (percentage of intervals) derived from instantaneous recording, rather than as raw binary or count data. As the response variables approximated a normal distribution and included repeated measures per individual, LMMs with individual identity as a random intercept were considered appropriate.

To address the research questions, “*How do captive chimpanzees at Fundació MONA respond to rosemary-scented enrichment objects?*” and “*Does exposure to rosemary alter the chimpanzees’ activity budgets, particularly in relation to stress-related and foraging behaviours?*”, two sets of linear mixed-effects models were constructed.

First, to evaluate the attractiveness of the enrichment, interaction frequency and percentage of intervals in contact with the socks were compared between the “romero” and “empty” conditions.

Second, to assess behavioural effects on activity budgets, models were fitted for each behavioural category comparing the “romero” and “nothing” conditions.

In all models, “condition”, “sex”, and “group” were included as fixed effects, and individual identity was included as a random intercept to account for repeated measures. For selected behaviours, additional covariates (sock interaction and sock contact) were included.

Stress-related behaviour was defined as a composite measure of abnormal, agonistic, and self-directed behaviours (see ethogram for details), following the definition applied by Alegre Maurer (2024) in visitor impact studies at Fundació MONA.

Affiliative interaction behaviour, defined as a composite measure of affiliative, grooming, and socio-sexual behaviours (see ethogram for details).

2.7 Ethical aspects

This study relied on non-invasive behavioural observation and naturalistic enrichment procedures, ensuring minimal interference with the chimpanzees’ daily routine. Participation in the enrichment was entirely voluntary, and no food deprivation or restraint was used. Socks

were safely prepared with safe amounts of rosemary and monitored by trained staff, and individuals could choose to ignore this enrichment.

This study received ethical approval from Fundació MONA's internal management team and was conducted in accordance with established guidelines for non-invasive behavioural research in primates. Because the study relied exclusively on passive observation without any manipulation, physical contact, restraint, or alteration of the animals' routine, no external ethical committee approval was required. Throughout the study, no chimpanzees were handled, sedated, injected, or subjected to any potentially painful or stressful procedures; therefore, the research did not constitute an animal experiment under EU Directive 2010/63/EU. Animal welfare remained the priority at all times, and the resident veterinarian confirmed that the project did not interfere with health, social stability, enrichment schedules, or daily husbandry routines. As such, the study adhered fully to best-practice ethical standards for behavioural research with captive primates.

3. Results

This section presents the behavioural responses of captive chimpanzees at Fundació MONA to olfactory enrichment with rosemary-scented socks. Results are structured into (1) interaction and contact with the enrichment objects and (2) the behavioural effects of olfactory enrichment on activity budgets.

“Sock contact” was quantified using an interval-based measure derived from instantaneous recording. Contact intensity was expressed as the proportion of observation intervals in which physical contact with the sock was recorded and standardised per hour of observation. This measure reflects relative contact frequency rather than continuous contact duration.

We defined three enrichment conditions: rosemary socks “romero”, control socks “empty”, and no socks “nothing”.

3.1 Interaction and contact with enrichment objects

Chimpanzees interacted significantly more frequently with rosemary-scented socks than with unscented control socks. A likelihood ratio test showed that a mixed-effects model including “condition” fitted the data significantly better than the null model ($\chi^2(1) = 10.39$, $p = 0.0016$), with higher interaction levels observed in the “romero” condition ($\beta = 0.41 \pm 0.13$, $t(150) = 3.22$).

Similarly, the percentage of intervals spent with socks by the chimpanzees was significantly higher in the “romero” condition compared to the “empty” condition ($\chi^2(1) = 6.43$, $p = 0.012$). The fixed-effect estimate confirmed that the scent of rosemary increased the percentage of intervals the chimps spent with the enrichment objects ($\beta = 2.07 \pm 0.82$, $t(150) = 2.54$).

“Sex” and “group” did not significantly predict either “interaction frequency” or “contact duration” (all $p > 0.05$). These findings indicate a clear behavioural preference for rosemary-scented enrichment objects.

Full model results are provided in Supplementary Tables S01–S02.

3.2 Behavioural effects of olfactory enrichment

Stress-related behaviour

A likelihood ratio test indicated that the full model significantly outperformed the null model containing only a random intercept for individual identity ($\chi^2(6) = 23.25$, $p < 0.001$). Type III analysis of variance revealed a significant main effect of “condition” on stress-related behaviour ($F(2, 231) = 4.45$, $p = 0.013$).

Post hoc comparisons using Holm-adjusted contrasts showed that stress-related behaviour was significantly lower in the “romero” condition compared to the “nothing” condition ($p = 0.012$). No significant difference was detected between the “empty” and “nothing” conditions, indicating that the reduction in stress was attributable to the scent of rosemary rather than the mere presence of the object.

In addition to “condition”, the percentage of intervals that were spent with the enrichment object was a significant predictor of stress-related behaviour ($F(1, 234) = 4.03$, $p = 0.046$). A higher percentage of intervals in contact with the rosemary socks, was associated with a small but consistent reduction in stress-related behaviour ($\beta = -0.0021 \pm 0.0010$). In contrast, the number

of sock interactions did not significantly predict stress levels ($p = 0.66$). “Sex” and “group” were not significant predictors (all $p > 0.1$).

These results indicate that both exposure to rosemary-scented enrichment and an increased percentage of intervals with the enrichment object could be linked with reduced stress-related behaviour in this context.

A visual representation of stress-related behaviour across experimental conditions is provided in Figure 2.

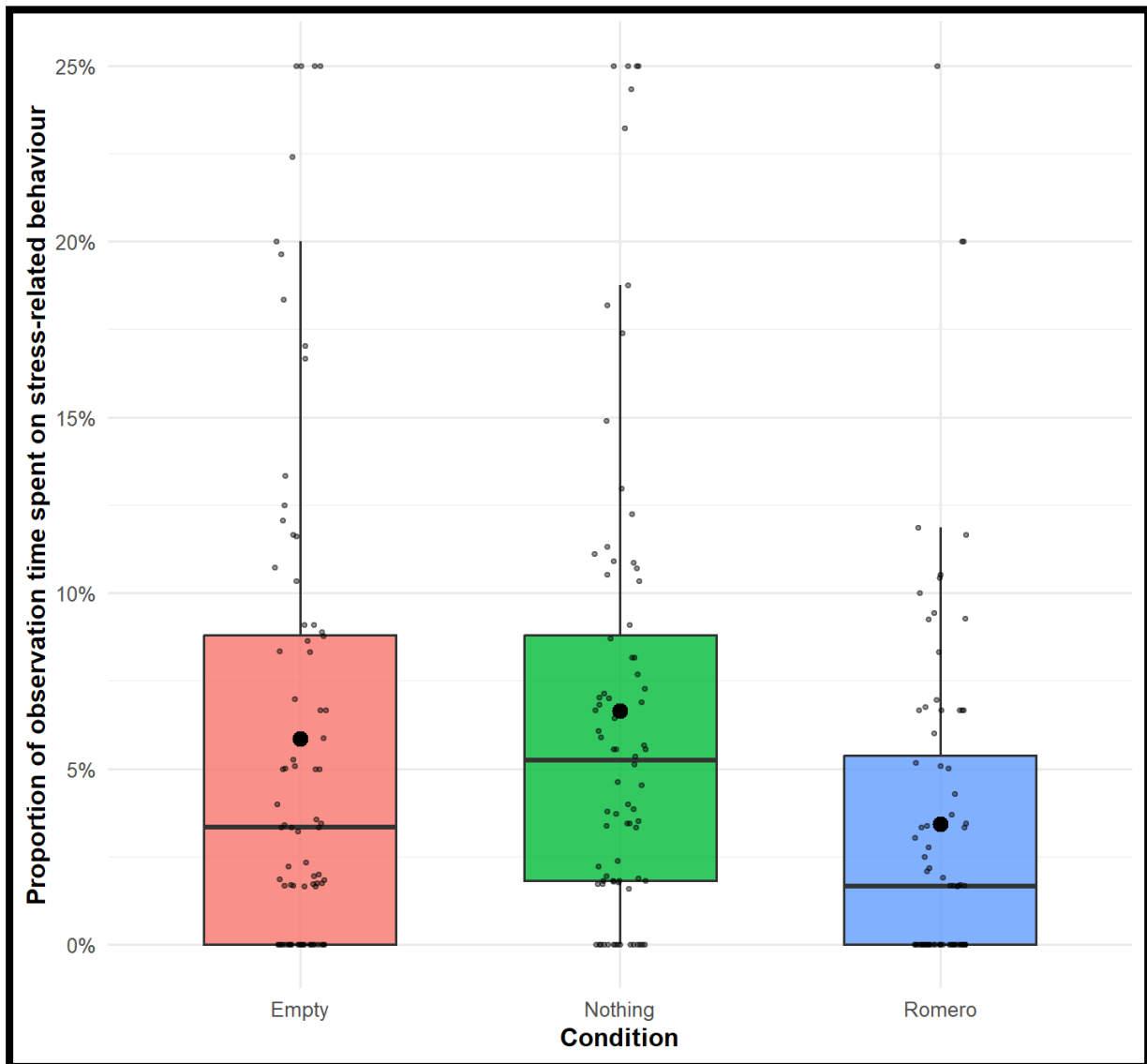


Figure 2. Presence of olfactory enrichment and stress behaviour

Foraging behaviour

Foraging behaviour differed significantly between experimental conditions. A likelihood ratio test comparing a null model with a full mixed-effects model showed a significant improvement in model fit ($\chi^2(3) = 10.85$, $p = 0.0126$).

Type III analysis of variance revealed a significant main effect of “condition” on foraging behaviour ($F(1, 230) = 9.80$, $p = 0.002$). Chimpanzees in the “romero” condition spent a significantly greater proportion of time foraging compared to the “nothing” condition ($\beta = 0.0396 \pm 0.0126$). “Sex” and “group” were not significant predictors.

When physical contact with the enrichment object was included as a covariate, an increase of the percentage of intervals was negatively associated with foraging behaviour ($p < 0.05$).

A visual summary of foraging behaviour across conditions is shown in Figure 3.

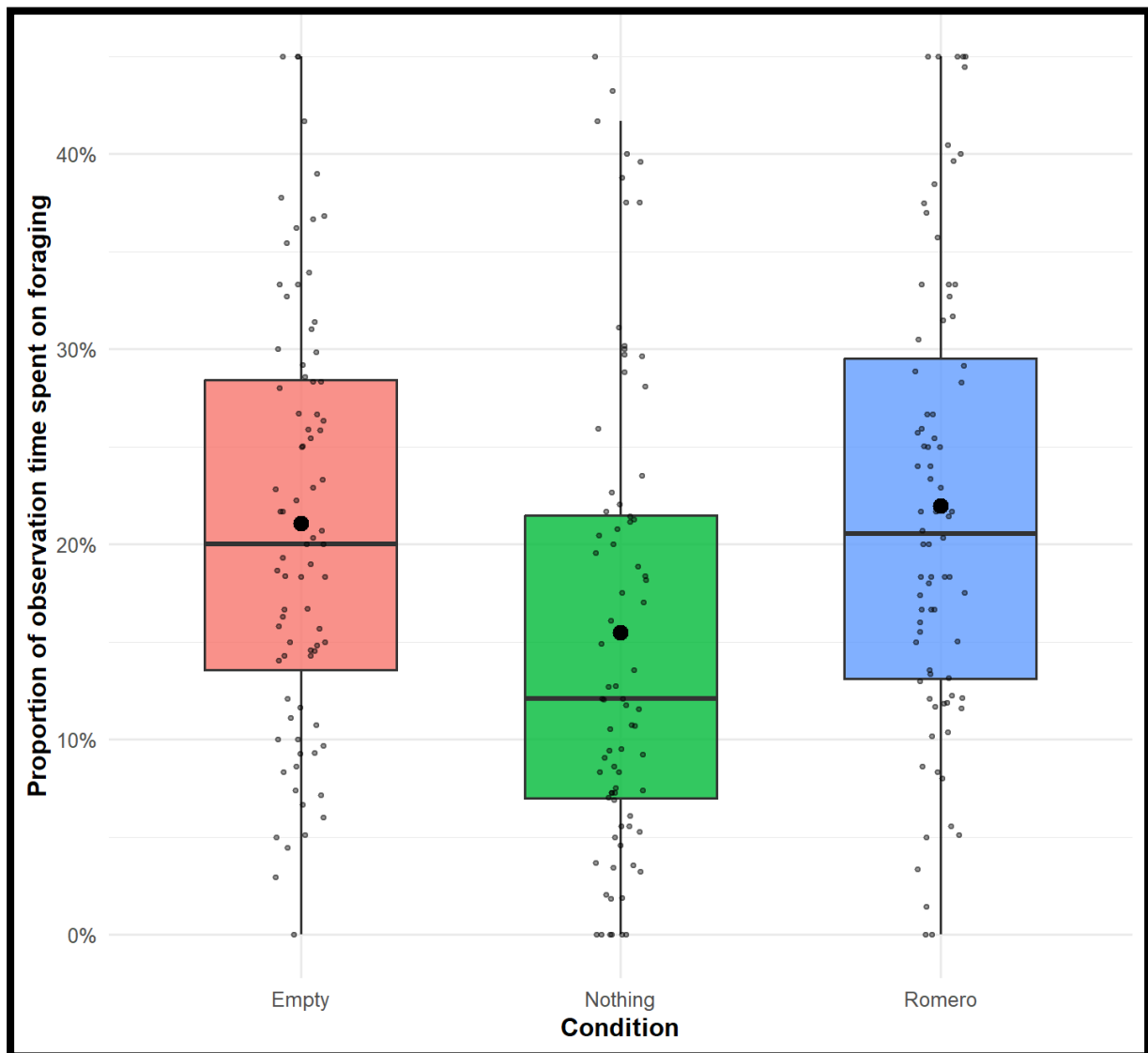


Figure 3. Presence of olfactory enrichment and foraging

Other behavioural categories

Affiliative interaction behaviour, defined as a composite of affiliative, grooming, and socio-sexual behaviours, did not differ significantly between conditions at the model comparison level (likelihood ratio test: $\chi^2(5) = 9.07$, $p = 0.11$). The same is true for inactivity behaviour: a comparison of the full model with the null model indicated no significant improvement in model fit (likelihood ratio test: $\chi^2(5) = 5.92$, $p = 0.31$).

Full model outputs for all behaviours are reported in Appendix 4. Supplementary Tables S01–S06.

4. Discussion

4.1 Overview of the main findings

The aim of this study was to evaluate the effects of olfactory enrichment with rosemary on the behaviour of captive chimpanzees, with a specific focus on foraging, (in)activity, affiliative, and stress-related behaviour. Linear mixed-effects models were used to compare behavioural responses under the rosemary-scented condition (“romero”) with two control conditions, while accounting for repeated measures at the individual level and controlling for sex and group membership.

Overall, the results demonstrate that olfactory enrichment influenced chimpanzee behaviour in a behaviour-specific manner. Stress-related behaviour was significantly reduced in the presence of rosemary compared to the no socks control, while foraging behaviour increased significantly with rosemary enrichment. In contrast, sex and group did not significantly predict variation in either stress-related or foraging behaviour. These findings suggest that olfactory enrichment with rosemary can have measurable and potentially beneficial effects on specific aspects of chimpanzee welfare.

In addition, rosemary-scented objects elicited significantly higher levels of interaction and a higher percentage of intervals were found where the chimpanzees were in contact with the rosemary socks compared to unscented controls. However the interaction or contact levels did not consistently link to behavioural changes, indicating that the mere presence (and scent in the air) of the rosemary enrichment was enough to have an effect on chimpanzee behaviour.

4.2 Effects of olfactory enrichment on stress-related behaviour

Stress-related behaviour occurred at relatively low levels across all experimental conditions, which is consistent with previous research reporting low baseline stress behaviours in the captive chimpanzee populations of MONA (Gil-Dolz et al., 2024). Nevertheless, a statistically significant reduction in stress-related behaviour was observed when rosemary was present compared to when it was not (“nothing” condition), indicating that olfactory enrichment may contribute to a calmer behavioural state even when baseline stress is already limited.

One potential explanation for this effect is that biologically relevant or novel odours may modulate emotional states by stimulating exploratory or investigative behaviour, thereby redirecting attention away from stress-related responses (Elwell & Vaglio, 2023). Rosemary has been associated with calming or anxiolytic effects in several mammalian species, including rodents and humans (Ferlemi et al., 2015; Shaw et al., 2007; Moss et al., 2003), although empirical evidence in non-human primates remains scarce (Elwell & Vaglio, 2023). The present findings therefore provide preliminary support for the hypothesis that plant-based olfactory stimuli can influence stress-related behaviour in chimpanzees.

Importantly, the “empty” condition did not consistently differ from the “nothing” condition, suggesting that the observed reduction in stress-related behaviour cannot be attributed solely to the presence of an object or experimental manipulation. Instead, the specific olfactory properties of rosemary appear to play a key role in eliciting behavioural change.

4.3 Effects of olfactory enrichment on foraging behaviour

In contrast to stress-related behaviour, foraging behaviour showed a clear and statistically significant increase under the rosemary condition compared to when no socks were present. This finding aligns well with existing literature by Wells (2009) and Vaglio et al. (2021) suggesting that enrichment strategies which stimulate sensory exploration can promote species-typical behaviours such as foraging.

The increase in foraging behaviour may reflect heightened exploratory motivation induced by the novel scent, encouraging individuals to investigate their environment more actively. From an animal welfare perspective, this is a positive outcome, as increased engagement in foraging-related activities is generally associated with enhanced behavioural diversity and improved psychological well-being in captive primates (Schapiro et al., 2014). This is widely considered an indicator of positive welfare (Mellor, 2016).

The “empty” condition showed intermediate levels of foraging behaviour, suggesting that object novelty alone may have some effect. However, the stronger and more consistent increase observed in the rosemary condition supports the conclusion that olfactory enrichment provides added value beyond non-scented control conditions.

4.4 Influence of sex and group

Neither sex nor group emerged as significant predictors of stress-related or foraging behaviour in the linear mixed-effects models. This suggests that the behavioural effects of rosemary enrichment were relatively consistent across males and females and across the studied social groups.

Although sex differences in enrichment responses have been reported in primates (Padrell et al., 2022), their absence in this study may be explained by the nature of the enrichment used. The rosemary-scented socks required minimal manipulation and primarily provided a passive olfactory stimulus, which may reduce the likelihood of differential engagement between individuals. In addition, prior familiarity with human-associated objects may have further reduced variability in responses. Finally, because the models accounted for repeated measures at the individual level, part of the individual variability was already controlled for statistically, which may also contribute to the absence of detectable sex or group effects.

4.5 Interaction and contact with rosemary-scented socks

Rosemary-scented enrichment objects elicited significantly higher levels of interaction and physical contact compared to unscented control objects, indicating that the scent increased the attractiveness of the enrichment items. However, analyses examining the relationship between interaction frequency, percentage of interval contact, and behavioural outcomes revealed no significant predictive effects within the rosemary condition.

Importantly, foraging behaviour did not vary systematically with levels of interaction or contact, indicating that increased foraging under the rosemary condition was likely driven by passive olfactory exposure rather than direct engagement with the enrichment devices. This supports the notion that olfactory enrichment may operate at a group-wide level, benefiting individuals regardless of their degree of physical interaction or contact with the enrichment items.

4.6 Description of observations and individual variations

In addition to the quantitative analyses, a selection of relevant aspects of the observations is described to illustrate the individual ways in which the chimpanzees at Fundació MONA interacted with the socks provided during the study. For this descriptive section, no distinction is made between empty socks and rosemary-scented socks; the aim is solely to provide the reader with a more tangible impression of the diversity of individual responses observed during the enrichment sessions.

Each morning, upon exiting their indoor enclosures, the chimpanzees of the Mutamba group consistently prioritised food intake. Interaction with the socks typically occurred later, once feeding had subsided. Some individuals, however, integrated the socks into their routine almost immediately. Africa, for instance, was observed on several occasions carrying a sock with her while still foraging. Both Africa and Waty showed a tendency to keep socks close to them during periods of rest, often holding them while lying in their preferred resting locations, such as a tyre. Africa displayed particularly elaborate manipulation behaviour: she frequently emptied the sock of its content, replaced the rosemary and straw, and occasionally attempted to add additional enrichment materials, such as sheets, into the sock. When multiple socks were available, she was observed placing one sock inside another. Socks were often kept near her during feeding, resting, and locomotion. During the first days of the experiment, both Africa and Waty were seen consuming small amounts of rosemary after shaking it out of the sock and leaving it on platforms frequented by other group members.

The dominant male, Bongo, also showed marked interest in the socks. He was regularly observed carrying them in his mouth or holding them with his foot while foraging, and on several occasions placed a sock over his foot, walking around with it during the afternoon. Juanito examined a rosemary sock intensively on one occasion and consumed some of the herbs, although this behaviour was not repeated. He did, however, carry socks in his mouth on several subsequent occasions. Marco initially showed little interest but later began to empty the socks and place them on his foot, a behaviour that recurred on following days when socks were available. Within the Mutamba group, all individuals engaged with the socks to some degree, commonly holding them while walking or resting, emptying them, or placing them on hands or feet.

A different interaction pattern was observed in the Bilinga group. Cheeta showed minimal interest, interacting briefly with a sock only once or twice over the four-week experimental period. Coco, in contrast, became increasingly engaged from the second day of rosemary sock exposure onward. She frequently carried a sock against her hip and repositioned it onto her abdomen when resting, a behaviour observed across multiple days. The males in this group appeared particularly adept at using the socks. Nico was often seen wearing a sock on his hand or arm, even retaining it during movement to and from medical procedures; when the sock was removed, he would promptly retrieve another upon returning to the enclosure. Tom regularly picked up socks, smelled and emptied them, and alternated between carrying them in his mouth or hand while foraging, before keeping them close during resting periods. Victor immediately placed socks on his foot, sometimes positioning them only on a single toe, and continued to walk with them until they fell off or had to be removed for climbing.

Together, these qualitative observations highlight substantial individual variation in the way chimpanzees engaged with the socks, ranging from brief exploratory contact to prolonged and repeated manipulation. While these behaviours were not subjected to statistical analysis, they provide valuable contextual insight into how enrichment items were incorporated into the daily routines of different individuals and social groups.

4.7 Methodological considerations and limitations

Several limitations should be considered when interpreting the results of this study. First, the relatively small number of individuals limits the generalisability of the findings. Although repeated observations increased the overall data volume, individual differences in behavioural tendencies may still have influenced the results. Although the statistical models accounted for repeated measures at the individual level by including individual identity as a random effect, residual individual variability may still be present.

Second, behavioural data were collected using instantaneous sampling, which provides an efficient overview of activity budgets but may underestimate short-duration or low-frequency behaviours. This limitation is particularly relevant for stress-related behaviours, which often occur briefly and sporadically.

Thirdly, observations were not conducted blind to the experimental conditions. Observer bias is not to be underestimated for this small experiment.

Fourth, the study focused on short-term behavioural responses. It remains unclear whether the observed effects of rosemary enrichment would persist over longer periods or diminish due to habituation. Long-term studies are therefore needed to assess the sustained effectiveness of olfactory enrichment strategies.

Finally, only one type of olfactory stimulus was examined. Different scents may elicit different behavioural responses, and individual preferences or prior experiences could modulate reactions to specific odours.

4.8 Implications for captive chimpanzee welfare and management

Despite these limitations, the findings of this study have important implications for the management and welfare of captive chimpanzees. Olfactory enrichment is relatively easy to implement, low-cost, and minimally invasive, making it an attractive addition to existing enrichment programmes.

The observed reduction in stress-related behaviour and increase in foraging behaviour suggest that rosemary enrichment may enhance behavioural diversity and promote more positive welfare. Incorporating olfactory enrichment alongside structural, cognitive, and feeding-based enrichment may therefore contribute to a more stimulating and welfare-oriented captive environment.

Olfactory and ingestive enrichment with botanical items such as leaves from aromatic plants (e.g. rosemary) align well with the behavioural ecology and natural foraging strategies of chimpanzees (Celli et al., 2003). Offering rosemary leaves during foraging puzzles or in drinking water may encourage exploratory and species-typical behaviours, contributing to psychological well-being (Freyman et al., 2024). The complex aromas and flavours serve as both sensory and gustatory enrichment, potentially reducing stereotypes or helping modulate stress in captivity (Elwell & Vaglio, 2023). Field observations underscore the flexibility primates exhibit in

experimenting with new plant resources when ill or stressed; thus, rosemary could be a viable addition to welfare strategies in managed care settings (Ghasemzadeh Rahbardar et al., 2020; Freymann et al., 2025). Future investigations might address dosing parameters, long-term safety, and optimal delivery modes in captive primates.

4.9 Future research directions

Future research should explore the effects of a wider range of olfactory stimuli, including scents with different ecological or biological relevance to chimpanzees. Longitudinal study designs would allow assessment of habituation effects and long-term welfare outcomes.

Combining behavioural observations with physiological measures of stress, depending on the methods used and being aware of the discussions currently undertaken about this topic, could also provide a more comprehensive understanding of how olfactory enrichment influences stress responses (Capitanio et al., 2023). Additionally, investigating individual differences in scent preferences may help optimise enrichment strategies for diverse captive populations.

5. Conclusion

This study demonstrated that rosemary-based olfactory enrichment elicited clear behavioural responses in captive chimpanzees at Fundació MONA. Chimpanzees showed a significant preference for the rosemary-scented enrichment objects compared with unscented controls, indicating that the scent itself functioned as an attractive stimulus.

More importantly, exposure to rosemary was associated with a significant reduction in stress-related behaviour and a significant increase in species-typical foraging behaviour. These findings suggest that olfactory enrichment can positively influence relevant behavioural indicators of welfare in sanctuary-housed chimpanzees.

No significant effects of sex or group membership were detected, indicating that this enrichment strategy may be broadly applicable across different demographic categories.

Future research could benefit from longer-term studies, repeated exposure phases, and the inclusion of additional olfactory stimuli to assess habituation effects and scent-specific responses.

Overall, rosemary-based olfactory enrichment represents a practical, low-cost and minimally invasive welfare tool that promotes psychological well-being and behavioural diversity, and can complement existing enrichment programmes in captive primate management and rehabilitation settings.

6. List of photos, tables and figures

PHOTO 1. Enclosure 1, from visitors viewpoint.

PHOTO 2. Enclosure 1, from observation tower. On the right there is the visitors viewpoint.

PHOTO 3. Enclosure 1, from observation tower. In the back Enclosure 2, with an electric fence in between.

PHOTO 4. Enclosure 2, from observation tower, including the observation material

PHOTO 5. Enclosure 2.

PHOTO 6. This map of the two outdoor enclosures shows both groups, Mutamba and Bilinga, separated by an electric fence.

PHOTO 7: Overview of all enrichments used during observation period.

PHOTO 8: Socks in enclosure 2 in the morning before the chimpanzees come out.

PHOTO 9: Observer

TABLE 1. Summary of the main information available for each chimpanzee in our study groups, comprising its group at MONA, its sex, age and the info about the individual's previous (living) conditions, at time of publication.

Figure 1. Print screen of ZooMonitor screen during observations

Figure 2. Presence of olfactory enrichment and stress behaviour

Figure 3. Presence of olfactory enrichment and foraging

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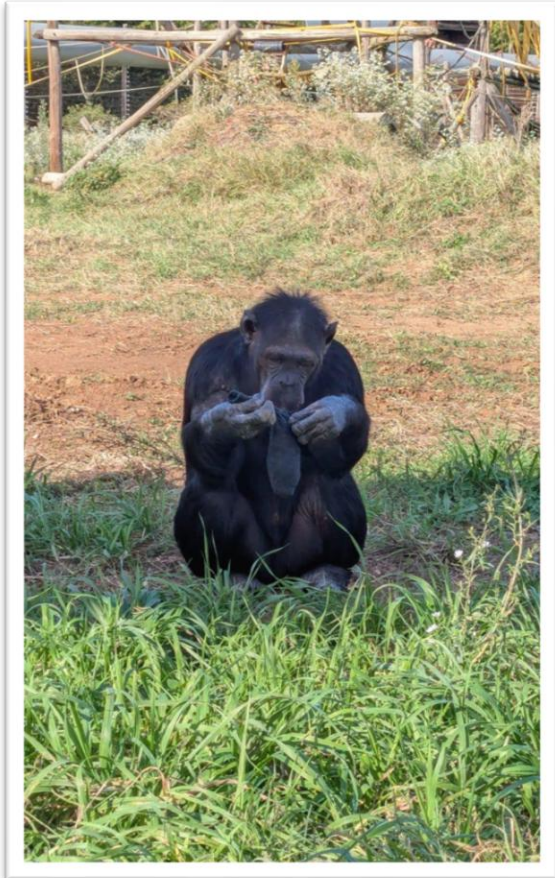
8. Appendices

8.1 Appendix 1. Photographical overview of the chimpanzees.

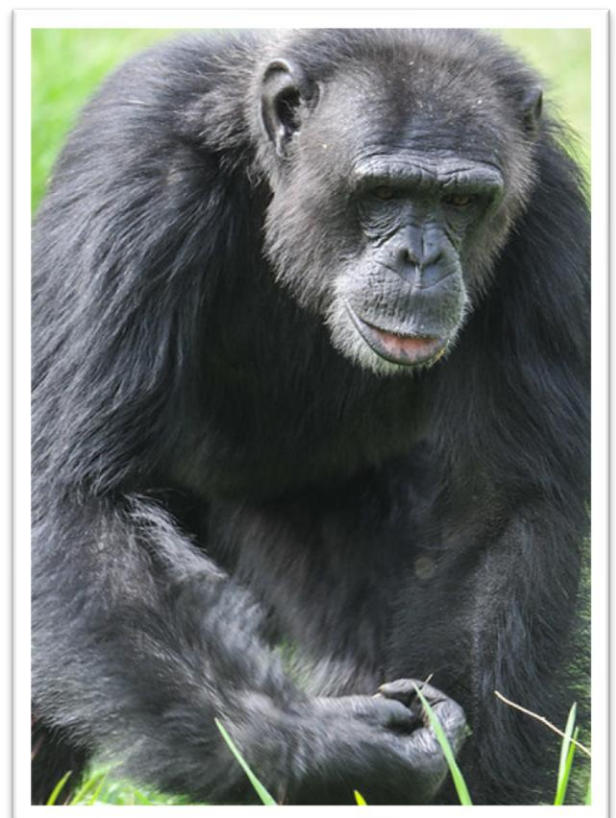
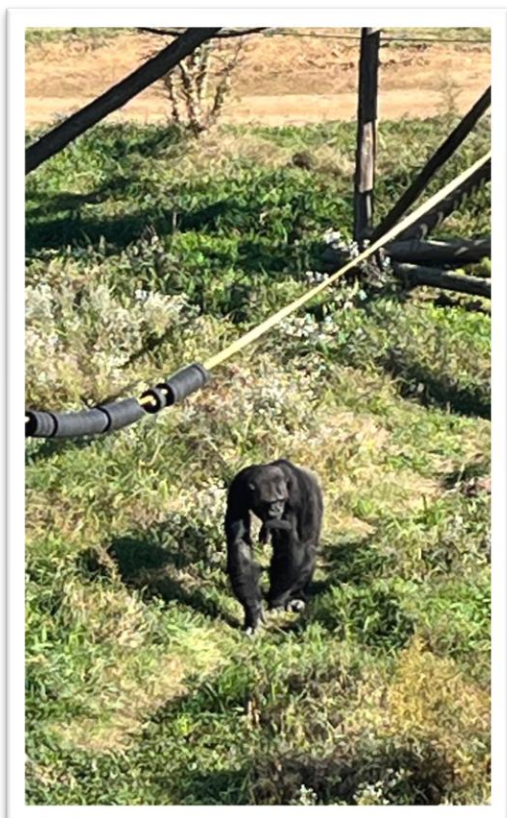
Identifying all chimpanzees with socks if possible, in Mutamba and Bilinga. All are © Ann Ieven.

Mutamba

Africa



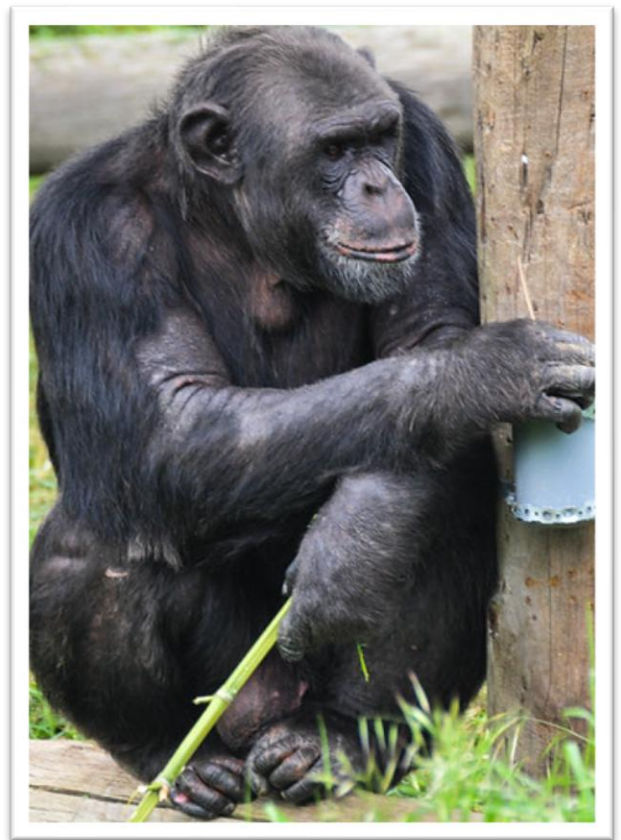
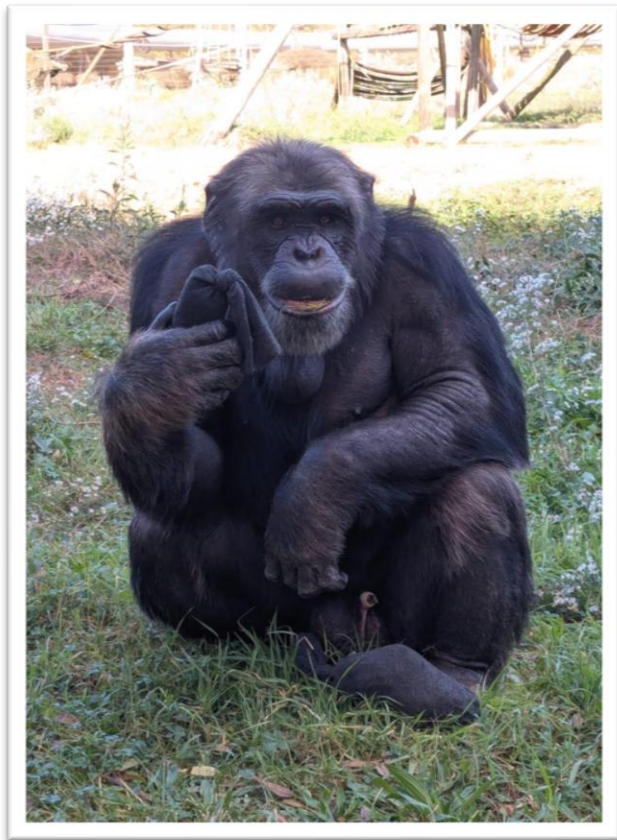
Bongo



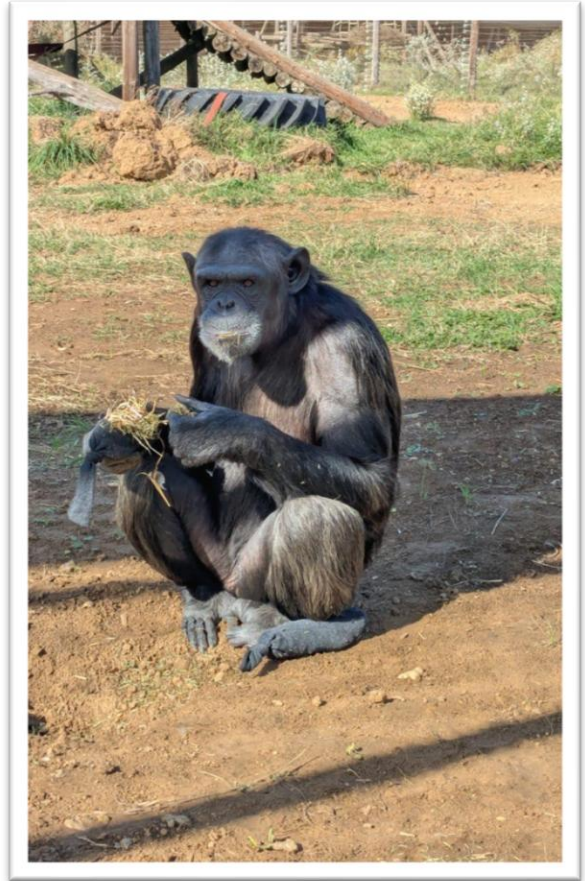
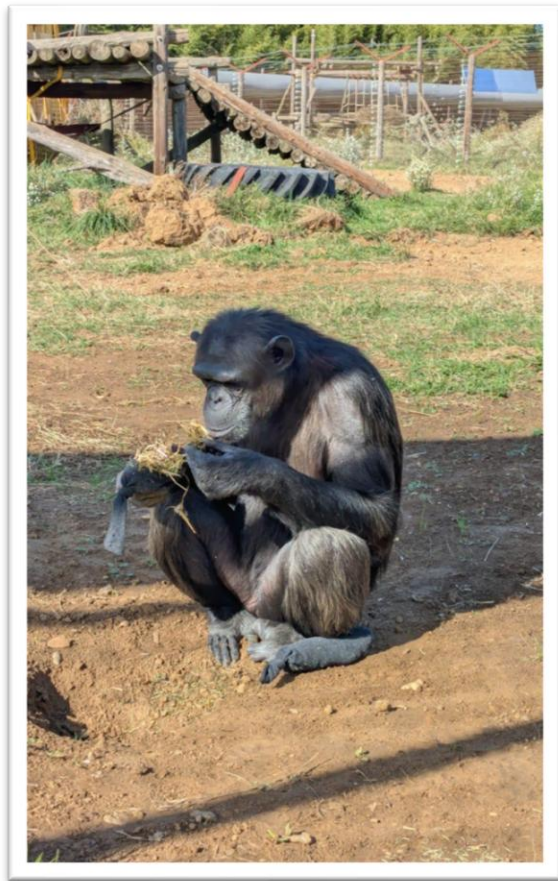
Marco



Juanito

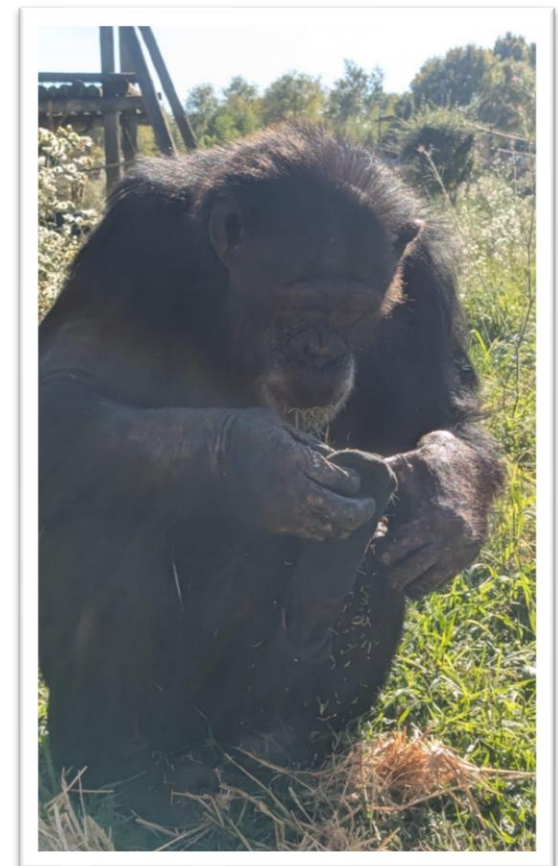
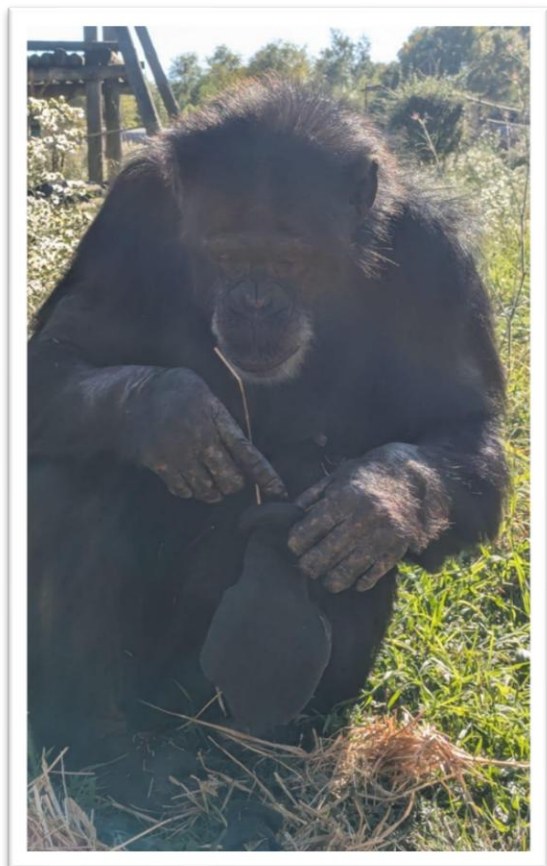


Waty

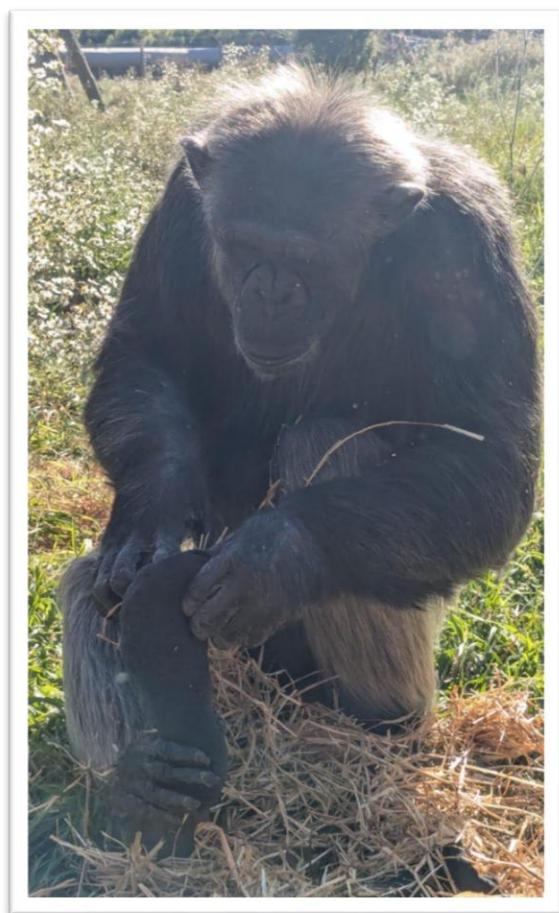
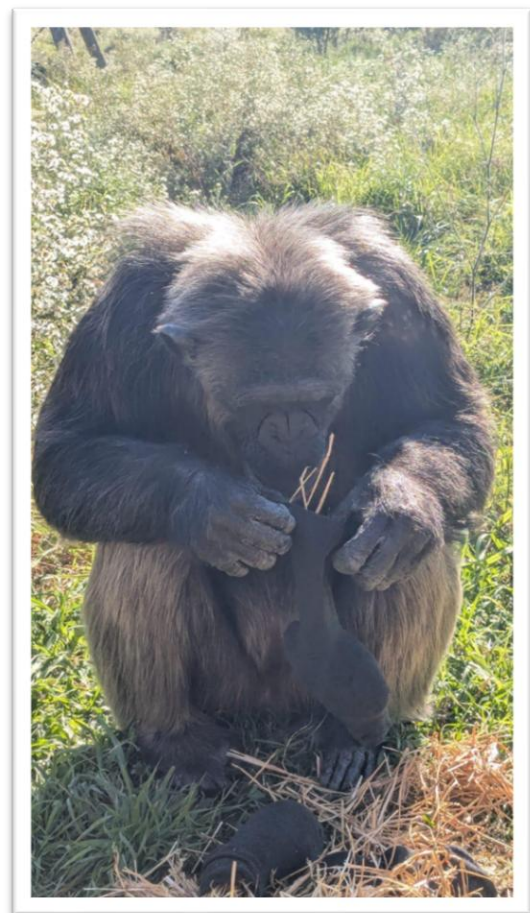


Bilinga

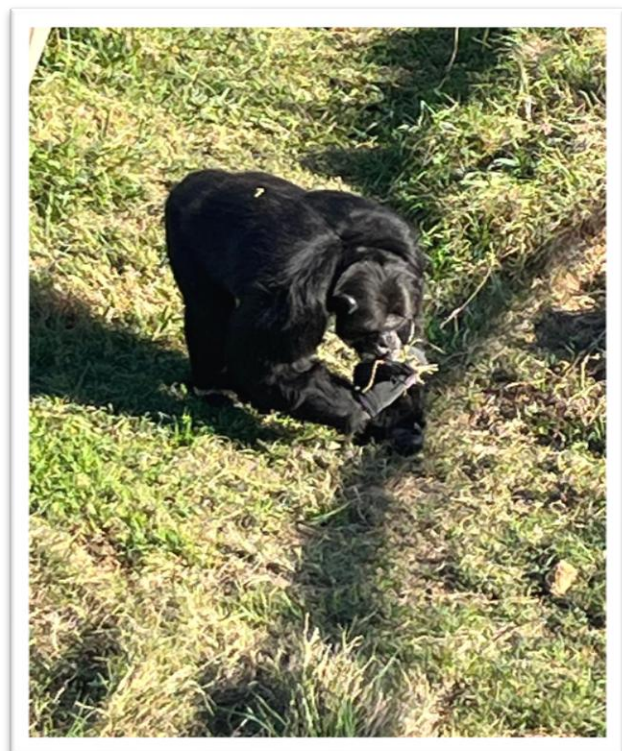
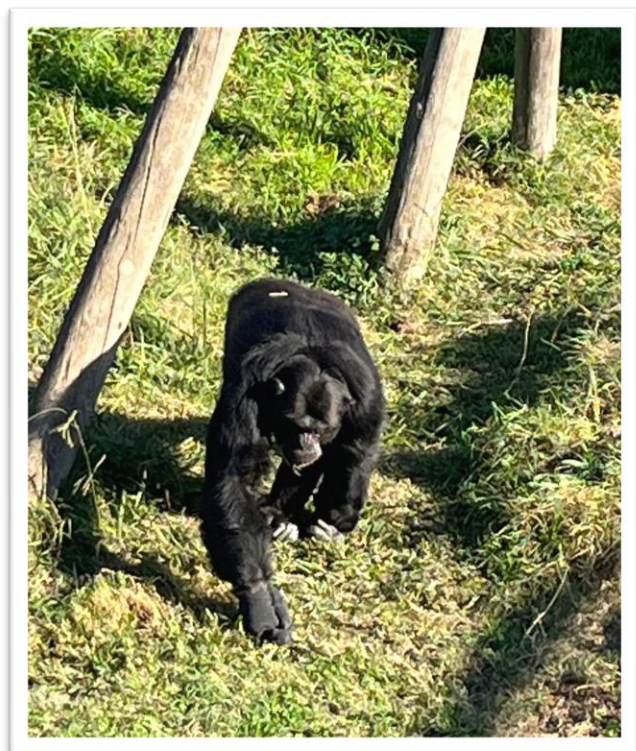
Cheeta



Coco



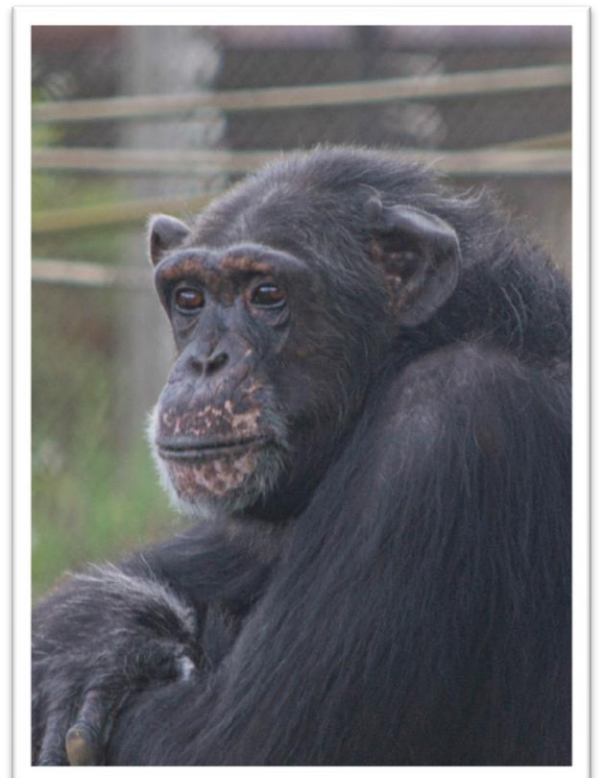
Nico



Tom



Victor



8.2 Appendix 2. Photographical overview of the techniques used to prepare the socks.







8.3 Appendix 3. Program of daily enrichment

Date of installation	Kind of enrichment	Group	Enclosure	Amount	Enrich Fixation	Enrich Time	Amount per chimp	Category
1/11/2025	PVC tubes with holes (small ones) and bamboo	Mutamba	Exterior 1	5	Stationary	Antes de salir	1	Simple extraction
1/11/2025	PVC tubes with holes (small ones) and bamboo	Bilinga	Exterior 2	4	Stationary	Antes de salir	0.8	Simple extraction
2/11/2025	Enriquitelas	Mutamba	Exterior 1	15	Mobile	Antes de salir	3	Simple extraction
2/11/2025	Enriquitelas	Bilinga	Exterior 2	15	Mobile	Antes de salir	3	Simple extraction
3/11/2025	Hose cubes	Mutamba	Exterior 1	7	Stationary	Antes de salir	1.4	Simple extraction
4/11/2025	Flowerpots/pots	Mutamba	Exterior 1	10	Mobile	Antes de salir	2	Simple extraction
4/11/2025	Flowerpots/pots	Bilinga	Exterior 2	10	Mobile	Antes de salir	2	Simple extraction
5/11/2025	Browsers	Bilinga	Exterior 1	5	Stationary	Antes de salir	1	Complex extraction
6/11/2025	Tennis balls	Mutamba	Exterior 1		Mobile	Antes de salir	0	Simple extraction
6/11/2025	Tennis balls	Bilinga	Exterior 2		Mobile	Antes de salir	0	Simple extraction
7/11/2025	Hose lines	Mutamba	Exterior 1	5	Stationary	Antes de salir	1	Simple extraction
7/11/2025	Hose lines	Bilinga	Exterior 2	5	Stationary	Antes de salir	1	Simple extraction
9/11/2025	Puzzle Exteriors	Mutamba	Exterior 1	1	Stationary	Antes de salir	0.2	Complex extraction
9/11/2025	Puzzle Exteriors	Bilinga	Exterior 2	1	Stationary	Antes de salir	0.2	Complex extraction

10/11/2025	Hose cubes	Mutamba	Exterior 1	7	Stationary	Antes de salir	1.4	Simple extraction
10/11/2025	Hose cubes	Bilinga	Exterior 2	7	Stationary	Antes de salir	1.4	Simple extraction
11/11/2025	Black/blue disks	Mutamba	Exterior 1	5	Stationary	Antes de salir	1	Simple extraction
11/11/2025	Black/blue disks	Bilinga	Exterior 2	5	Stationary	Antes de salir	1	Simple extraction
12/11/2025	Envelopes (Chimps)	Mutamba	Exterior 1	10	Stationary	Antes de salir	2	Simple extraction
13/11/2025	Kongs	Mutamba	Exterior 1	7	Stationary	Antes de salir	1.4	Simple extraction
13/11/2025	Kongs	Bilinga	Exterior 2	7	Stationary	Antes de salir	1.4	Simple extraction
14/11/2025	Cloth packages	Mutamba	Exterior 1	10	Mobile	Antes de salir	2	Simple extraction
14/11/2025	Cloth packages	Bilinga	Exterior 2	10	Mobile	Antes de salir	2	Simple extraction
15/11/2025	Termite mound	Mutamba	Exterior 1	1	Stationary	Antes de salir	0.2	Complex extraction
15/11/2025	Tennis rope	Bilinga	Exterior 2	8	Stationary	Antes de salir	1.6	Simple extraction
17/11/2025	Browsers	Mutamba	Exterior 1	5	Stationary	Antes de salir	1	Complex extraction
17/11/2025	Browsers	Bilinga	Exterior 2	5	Stationary	Antes de salir	1	Complex extraction
18/11/2025	Puzzle Exteriors	Mutamba	Exterior 1	1	Stationary	Antes de salir	0.2	Complex extraction
18/11/2025	Puzzle Exteriors	Bilinga	Exterior 2	1	Stationary	Antes de salir	0.2	Complex extraction
18/11/2025	Flowerpots/pots	Mutamba	Exterior 1	10	Mobile	Antes de salir	2	Simple extraction
18/11/2025	Flowerpots/pots	Bilinga	Exterior 2	10	Mobile	Antes de salir	2	Simple extraction
19/11/2025	Boxes	Mutamba	Exterior 1	5	Mobile	Antes de salir	1	Simple extraction

19/11/2025	Boxes	Bilinga	Exterior 2	5	Mobile	Antes de salir	1	Simple extraction
20/11/2025	PVC tubes with holes (small ones) and bamboo	Mutamba	Exterior 1	5	Stationary	Antes de salir	1	Simple extraction
20/11/2025	PVC tubes with holes (small ones) and bamboo	Bilinga	Exterior 2	4	Stationary	Antes de salir	0.8	Simple extraction
21/11/2025	Termite mound	Mutamba	Exterior 1	1	Stationary	Antes de salir	0.2	Complex extraction
21/11/2025	Tennis rope	Bilinga	Exterior 2	12	Stationary	Antes de salir	2.4	Simple extraction
22/11/2025	Hose lines	Mutamba	Exterior 1	5	Stationary	Antes de salir	1	Simple extraction
22/11/2025	Hose lines	Bilinga	Exterior 2	5	Stationary	Antes de salir	1	Simple extraction
23/11/2025	Short hoses	Mutamba	Exterior 1	15	Mobile	Con Scatter	3	Simple extraction
23/11/2025	Short hoses	Bilinga	Exterior 2	15	Mobile	Con Scatter	3	Simple extraction
24/11/2025	Hose cubes	Mutamba	Exterior 1	6	Stationary	Antes de salir	1.2	Simple extraction
24/11/2025	Hose cubes	Bilinga	Exterior 2	6	Stationary	Antes de salir	1.2	Simple extraction
25/11/2025	Tennis rope	Mutamba	Exterior 1	5	Stationary	Antes de salir	1	Simple extraction
26/11/2025	Envelopes (Chimps)	Mutamba	Exterior 1	10	Stationary	Antes de salir	2	Simple extraction
26/11/2025	Envelopes (Chimps)	Bilinga	Exterior 2	10	Stationary	Antes de salir	2	Simple extraction
27/11/2025	Black/blue disks	Mutamba	Exterior 1	5	Stationary	Antes de salir	1	Simple extraction
27/11/2025	Black/blue disks	Bilinga	Exterior 2	5	Stationary	Antes de salir	1	Simple extraction
28/11/2025	Browsers	Mutamba	Exterior 1	6	Stationary	Antes de salir	1.2	Complex extraction

28/11/2025	Browsers	Bilinga	Exterior 2	6	Stationary	Antes de salir	1.2	Complex extraction
29/11/2025	Tennis balls	Mutamba	Exterior 1	15	Mobile	Con Scatter	3	Simple extraction
29/11/2025	Tennis balls	Bilinga	Exterior 2	15	Mobile	Con Scatter	3	Simple extraction
30/11/2025	Kongs	Mutamba	Exterior 1	7	Stationary	Antes de salir	1.4	Simple extraction
30/11/2025	Kongs	Bilinga	Exterior 2	7	Stationary	Antes de salir	1.4	Simple extraction
1/12/2025	Enrquitelas	Mutamba	Exterior 1	5	Mobile	Antes de salir	1	Simple extraction
1/12/2025	Enrquitelas	Bilinga	Exterior 2	5	Mobile	Antes de salir	1	Simple extraction
2/12/2025	Boxes	Mutamba	Exterior 1	5	Mobile	Antes de salir	1	Simple extraction
2/12/2025	Boxes	Bilinga	Exterior 2	5	Mobile	Antes de salir	1	Simple extraction

8.4 Appendix 4. List of Supplementary tables S01 to S06

Table S01. Linear mixed-effects model results for sock interaction frequency

Response variable: sock interaction

Random effect: individual identity

Fixed effects: condition, sex, group

Predictor	Estimate (β)	SE	df	t value	p value
(Intercept)	–	–	–	–	–
Condition (Romero vs Empty)	0.41	0.13	150	3.22	0.0016
Sex	ns	–	–	–	> 0.05
Group	ns	–	–	–	> 0.05

Model comparison:

Likelihood ratio test vs null model:

$$\chi^2(1) = 10.39, p = 0.0016$$

Table S02. Linear mixed-effects model results for percentage of intervals with sock contact

Response variable: sock contact

Random effect: individual identity

Fixed effects: condition, sex, group

Predictor	Estimate (β)	SE	df	t value	p value
(Intercept)	–	–	–	–	–
Condition (Romero vs Empty)	2.07	0.82	150	2.54	0.012
Sex	ns	–	–	–	> 0.05
Group	ns	–	–	–	> 0.05

Model comparison:

Likelihood ratio test vs null model:

$$\chi^2(1) = 6.43, p = 0.012$$

Table S03. Linear mixed-effects model for stress-related behaviour (full model)**Response variable:** stress-related behaviour**Random effect:** individual identity**Fixed effects:** condition, sock_interaction, sock_contact, sex, group

Predictor	Estimate (β)	SE	df	t value	p value
(Intercept)	0.096	0.020	12.15	4.72	< 0.001
Condition: Nothing	0.0097	0.0099	230.6	0.99	0.325
Condition: Romero	-0.0216	0.0098	230.5	-2.20	0.029
Sock_Interaction	0.0028	0.0065	233.6	0.44	0.662
Sock_Contact	-0.0021	0.0010	234.0	-2.01	0.046
Sex (Male)	-0.028	0.021	10.1	-1.33	0.213
Group (Mutamba)	-0.034	0.021	10.2	-1.65	0.130

Table S04. Type III ANOVA for stress-related behaviour

Predictor	Num df	Den df	F value	p value
Condition	2	230.9	4.45	0.0127
Sock_Interaction	1	233.6	0.19	0.662
Sock_Contact	1	234.0	4.03	0.046
Sex	1	10.1	1.77	0.213
Group	1	10.2	2.71	0.130

Model comparison:

Likelihood ratio test vs null model:

$$\chi^2(6) = 23.25, p < 0.001$$

Table S05. Post hoc pairwise comparisons for Condition (stress-related behaviour)

Adjustment method: Holm

Contrast	Estimate	SE	z value	p value
Nothing – Empty	0.0097	0.0099	0.99	0.324
Romero – Empty	-0.0216	0.0098	-2.20	0.055
Romero – Nothing	-0.0314	0.0109	-2.89	0.0116

Table S06. Linear mixed-effects model for foraging behaviour (full model)

Response variable: foraging behaviour

Random effect: individual identity

Fixed effects: condition, sock_interaction, sock_contact, sex, group

Predictor	Direction of effect	Significance
Condition (Romero vs Nothing)	↑ Foraging	p = 0.002
Sock_Contact	↓ Foraging	<i>p < 0.05</i>
Sock_Interaction	No effect	ns
Sex	No effect	ns
Group	No effect	ns

Model comparison:

Likelihood ratio test vs null model:

$\chi^2(3) = 10.85$, $p = 0.0126$