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Handling of a Disbalanced Stick Tool in the Goffin's Cockatoo

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Özge Nasa BSc

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Contents

1. Zusammenfassung

Papageien (*Psittaciformes*) verfügen über einzigartige morphologische und verhaltensbiologische Merkmale, welche einen flexiblen und effizienten Werkzeuggebrauch, insbesondere mit Stöcken, ermöglichen, vergleichbar mit dem der Primaten. Bei werkzeugbenutzenden Arten kann die Beachtung gewichtsbezogener Hinweise die Effizienz der Nahrungssuche erhöhen, indem die energetischen Kosten der Werkzeugmanipulation minimiert werden. Frühere Forschungen haben gezeigt, dass Goffin-Kakadus (*Cacatua goffiniana*) gewichtsbezogene Hinweise erkennen und nutzen können, aber ihre Empfindlichkeit gegenüber unausgewogenen Objekten in funktionalen Werkzeugkontexten blieb bisher unerforscht. In dieser Studie wurde untersucht, wie Goffin-Kakadus mit einem unbalancierten Stockwerkzeug umgehen und welche individuellen Techniken sie anwenden, um ein bekanntes Stock-Werkzeug-Kasten-Problem zu lösen. Wir führten eine Reihe von Experimenten mit demselben allgemeinen Aufbau, aber unterschiedlichen Freiheitsgraden durch und untersuchten Veränderungen bei den Insertionstechniken und die Präferenzen der Handhabung des Stocks mit dem schwereren Ende im Schnabel - eine Strategie, welche die energetischen Kosten reduziert. Unsere Ergebnisse zeigten, dass Goffin-Kakadus auf Gruppenebene den Stock lieber so handhaben, dass der Schwerpunkt näher an der Greifstelle liegt. Darüber hinaus zeigten die Vögel hochgradig individualisierte Anpassungen der Technik, um neue Probleme zu lösen. Wir vermuten, dass Vögel, die ihre Techniken in dieser Situation nicht adaptierten, in der Lage sein könnten, dies unter erhöhten Einschränkungen der Lösungsmöglichkeiten zu tun. Diese Ergebnisse liefern den ersten Beweis dafür, dass Goffin-Kakadus auf eine unbalancierte Gewichtsverteilung in einem funktionalen Werkzeug achten und sich daran anpassen, was ihre Flexibilität bei der Problemlösung und ihre Sensibilität für physikalische Werkzeugeigenschaften unterstreicht.

2. Abstract

Parrots (*Psittaciformes*) possess unique morphological and behavioral traits that enable flexible and efficient tool use, particularly with stick tools, comparable to that observed in apes. In tool-using species, attending to weight-related cues can enhance foraging efficiency by minimizing the energetic costs of tool manipulation. Previous research has shown that Goffin's cockatoos (*Cacatua goffiniana*) can detect and utilize weight cues, but their sensitivity to unbalanced objects in functional tool contexts remains unexplored. This study investigated how Goffin's cockatoos handled a disbalanced stick tool and the individual techniques they employed to solve a familiar stick-tool box experiment. We conducted a series of experiments with the same general setup but varying degrees of freedom, examining changes in insertion techniques and preferences for handling the stick with the heavier end in their beaks—a strategy that reduces energetic costs. Our findings revealed that, at the group level, Goffin's cockatoos preferred to manipulate the stick with the center of mass closer to their gripping site. Additionally, the birds exhibited highly individualized technique adaptations to solve novel problems. We propose that birds that did not adapt their techniques in this setup might have the capacity to do so under increased task constraints. These results provide the first evidence of Goffin's cockatoos attending to and adapting to unbalanced weight distribution in a functional tool, highlighting their problem-solving flexibility and sensitivity to physical tool properties.

3. Introduction

Sticks represent a versatile tool within the animal kingdom, serving various functions such as self-scratching and fly-swatting (Chevalier-Skolnikoff & Liska, 1993) as well as probing for food (Estienne et al., 2017; Hernandez-Aguilar et al., 2007). The latter behavior has been extensively studied in our closest relatives, the chimpanzees, since Jane Goodall's groundbreaking observations in 1964 (Goodall, 1964). However, the discovery of tool manufacture and use in New Caledonian crows in 1996 (Hunt, 1996) has sparked increasing interest in avian tool use as well. Despite the deep evolutionary divergence between birds and primates, both in cognition and morphology, experiments have demonstrated comparable sophisticated tool use in birds, particularly in the manufacture and manipulation of stick tools (Hunt & Gray, 2003; Shaw, 2021).

Within the avian lineage, parrots (Order: *Psittaciformes)* have developed novel morphological features in the head, including two specialized jaw muscles (*M. ethmomandibularis* and *M. pseudomasseter*) (Tokita, 2004; Tokita et al., 2013) and a distinct head bone structure, such as a cranio-facial hinge and suborbital arches (Tokita, 2003). These unique jaw muscles give parrots significant power to close their lower beak while the suborbital arch reinforces the skull against the strength of these muscles. Working in tandem with the jaw muscles, the cranio-facial hinge is highly flexible and efficient at cracking large seeds and nuts (Carril et al., 2015; Demery et al., 2011). Recent high-resolution CT scans of the beak anatomy in the African grey parrot have revealed the distribution of nerve-rich papillae throughout the upper and lower mandible (Lessner et al., 2023). These papillae are crucial for mechanosensory perception, rendering the beak not only strong but also highly sensitive. In addition to their distinctive cranial, muscle and mechanosensory morphology, parrots possess specialized intrinsic tongue muscles, which afford them remarkable flexibility comparable to that observed in mammals (Gedam et al., 2022). This combination of head structures forms a versatile feeding apparatus, which enables a wide range of functions.

The observations of seed shelling behavior in wild Goffin's Cockatoos (*Cacatua goffiniana*, Goffin's hereafter) (Mioduszewska et al., 2022) demonstrate the intricate interplay between the aforementioned systems. This sophisticated mechanism is employed not only for direct shelling but the animals also appear to be able to readjust their feeding apparatus for a novel purpose: The manipulation of tools used to open nuts. In two distinct habitats (the endemic Tanimbar/Indonesia habitat and the novel Singapore habitat), wild Goffin's have been observed to modify small wooden fragments into tools by maneuvering them with their tongue inside the oral cavity. This process bears similarities to their seed-shelling behaviour (Mioduszewska et al., 2022; O'Hara et al., 2021). This meticulous manufacturing process is followed by a distinctive handling technique, whereby the tool is pressed against the upper beak tip with the tongue, in contrast to the method employed by tool-using passerines, which utilize the lower mandible (Matsui et al., 2016; Rutz et al., 2016; Tebbich et al., 2002).

Specifically, to open a Waiwai fruit on Tanimbar, O'Hara et al. (2021) observed a detailed, sequential process involving the manufacture and use of three different types of tools, each adapted to specific stages of the task, by two wild-caught Goffin's. In a sequential process, sturdy wedge-like tools were first inserted into the dorsal side of the fruit to widen the exposed fissure. Sharp, knife-like tools were then employed to pierce the mantle, allowing access to the fruit's contents and severing filaments. Finally, medium spoon-like tools were used to horizontally scoop out the fruit contents. Throughout the extraction process, the endocarp and the tools were dynamically aligned. The behavior of the Goffin's seemingly demonstrates advanced problem solving and motor control, adapting their tool use based on the characteristics and challenges of the fruit. This use of multiple tools in a hierarchical and flexible manner demonstrates a sophisticated understanding of object relations.

These relatively recent observations in the wild underscore the Goffin's capacity for innovation and adaptation in the use of complex stick tools, a capacity previously documented in experiments with captive, human-raised Goffin's.

Prior to the observations by O'Hara et al. (2021) of tool use in wild Goffin's, a notable case involved a captive Goffin named Figaro. In 2012, Figaro was observed spontaneously innovating tool use, a behavior not previously documented in this species (Auersperg et al., 2012). He successfully and consistently created and utilized stick-type tools to retrieve food, demonstrating the ability to manufacture these tools from two different materials and employing various steps and techniques. This unprecedented behavior sparked significant interest, leading to numerous follow-up studies aimed at understanding the mechanisms underlying this capability (Auersperg et al., 2014, 2016, 2018; Rössler et al., 2020).

One of these studies further investigated the social transmission of this individual innovation (Auersperg et al., 2014). Here, Figaro was used as a demonstrator in the control group, where subjects could watch him successfully manufacture stick tools and retrieve a nut from a mesh wired box (Auersperg et al., 2012). This resulted in 3 more male tool users who learned to emulate rather than imitate Figaro's demonstrations (Auersperg et al., 2014). Their techniques for retrieving the nut were very different, even though they all had the same demonstrator with one technique: While inserting the stick, Kiwi and Dolittle always held the stick between the upper and lower mandible as Figaro did, whereas Pipin placed the tool on the ground and began to slide the tool through the mesh entrance by flicking his tongue to move the stick forward. In addition, while Figaro inserted the tools at different grid heights, constantly repositioning the stick tip in response to the movement of the reward, all three observers kept the tools on the ground and scooped the food out with fast, lever-like motions caused by applying momentum to the proximal end of the tool.

Such individual differences in technique were also evident in a more advanced composite tool task experiment (Osuna-Mascaró et al., 2022). In this experiment, birds were presented with a puzzle box requiring sequential tool use: first inserting a ball into a box, then using a stick to push the ball across a carpeted surface into left or right openings, resembling a golf-like task. Three birds became consistently successful at retrieving the reward yet demonstrated significant differences in the insertion technique of the second tool, the stick. Figaro held the rear end of the stick toward his inner upper beak with his tongue, balancing the position of the tongue and head to allow mostly vertical stick movements; Fini gripped the stick by the front end, inserted a short portion with a head movement, and then used her tongue to push the stick with repeated thrusts; Pipin began the insertion with a leg grip and used his tongue to guide the stick toward the target, switching to a beak hold similar to Figaro's technique after completing the insertion. This variability in techniques suggests individual innovations rather than stereotypical behavior and highlights the Goffin's capacity for spontaneous innovative tool use driven by general cognitive processing.

Both studies demonstrate that while the general concept of a problem-solving task can be learned through social observation, the actual problem-solving process involves innovative behavior leading to the development of individual techniques. Once a solution is successfully discovered, it seems that the specific technique used is reinforced and becomes the preferred method for that individual, indicating a learning process based on strategic exploration and rapid reinforcement rather than through social learning (Bandini & Tennie, 2020). Ecologically, individual variation in problem-solving within a group is influenced by multiple factors (Ramsey et al., 2007). Biotic factors include sex, age, social group dynamics, genetics, and tendencies towards neophobia versus neophilia (Greenberg, 2012), as well as intraspecies competition for resources. Abiotic factors encompass the environment in which an animal is raised and forages (Ramsey et al., 2007).

For explorative foragers, complex tool use represents an advanced adaptation for enhancing foraging efficiency (Huber & O'Hara, 2021). In contrast, the assessment of weight, whether of food or tools, appears to be a more rudimentary aspect within optimal foraging theory, indicating that even non-tool-using animals possess the ability to discriminate weight (Heinrich et al., 1997; Jablonski et al., 2015; Pratt, 1938; Schmitt et al., 2013). Understanding how animals perceive and use weight information is critical for elucidating the evolution of weight-related cognition and for improving the efficiency of their behaviors. Most weight discrimination studies have been conducted on primates, revealing unexpected challenges in learning weight discrimination tasks (Massaro et al., 2012; Schrauf et al., 2012; Schrauf & Call, 2009). In contrast, the few comparable studies conducted on corvids and parrots have demonstrated their ability to effectively discriminate between objects of different weights (Jelbert et al., 2019; M. L. Lambert et al., 2017; Neilands et al., 2016). In an exchange paradigm study, apes learned to discriminate between 2 visually identical objects varying only in weight with an average of 331 trials to reach criterion (Schrauf & Call, 2009). However, only 3 bonobos and 2 orangutans successfully learned the weight discrimination task out of the 5 orangutans, 5 bonobos, and 2 gorillas tested. A comparable study conducted with Goffin's cockatoos revealed that 7 out of 8 subjects successfully discriminated between two visually identical objects differing in weight, requiring an average of just 60 trials to reach criterion (P. J. Lambert et al., 2021). This performance surpassed that of the apes, requiring approximately 81% fewer trials. These findings have been attributed to the heightened sensitivity to weight cues in flying animals, as the energetic costs associated with object transport are likely more critical for them, influencing their decision-making processes.
In a follow-up experiment by Adelmant et al. (2024), Goffin's cockatoos demonstrated not only the ability to learn general weight discrimination but also a functional and applied understanding of weight. The researchers conducted a series of binary choice experiments in which the birds chose between two identical objects that differed only in total weight or weight balance, both of which were equally rewarded. They found that Goffin's cockatoos preferred to carry lighter objects over heavier ones in both walking and flying modes. However, there was no difference in preference for same-weight objects that were either proportionally or disproportionately weighted. This suggests that Goffin's cockatoos can evaluate weight cues and use this evaluation to make decisions about object transport.

This study aimed to investigate the intersection between subject-specific insertion techniques of a stick tool and the weight discrimination abilities using a disbalanced stick tool. The Goffin's cockatoo serves as an ideal model for this research due to its proven capacity to assess weight cues and its remarkable ability to use stick tools in various forms, exhibiting individual differences in technique repertoire.

First, by using a straightforward stick-tool-box experiment with a balanced wooden stick tool, we sought to qualitatively describe the individual differences in techniques among 11 subjects. This aspect was previously addressed superficially in previous studies (Auersperg et al., 2014; Osuna-Mascaró et al., 2022), which only compared up to three subjects at a time. We expected that our study would provide insights into the individual differences, possible patterns, and their impact on the effectiveness of solving the stick-tool-box tasks.

In the second experiment, we modified the initial setup by introducing an unbalanced stick, resembling the one used previously but with one side significantly heavier. Additionally, the box was altered to feature two different types of openings for entry: one horizontal and one vertical. The horizontal opening represented a reduced degree of freedom, as the absence of lateral constraints, such as those present in the hole opening of the Base Technique test, shifted the control of lateral movements of the box to the subject. Furthermore, the vertical opening represented an additional reduction in degree of freedom, as the stick no longer had a surface to rest on at the opening, requiring the subject to control the full weight of the stick to complete the trial. This was done to assess the subjects' reactions and adaptations to these two major changes simultaneously.

We hypothesized that these modifications would prompt the birds to adjust their previously established techniques to accommodate the novel box and the added complexities. Specifically, in *Prediction 1)*, we predicted that when the birds need to fully control the tool (as required by the vertical slit), they would be more likely to modify their insertion technique compared to the horizontal slit, which provided support during tool use.

In *Prediction 2)*, we anticipated that, over time, the subjects would show a preference for completing the trials with the light end of the unbalanced stick inside the box at a level above chance. This preference would likely arise because controlling the heavier end with their beak is easier due to its physical properties (the center of mass hypothesis; D. Kleppner & R. Kolenkow (2014)) and is therefore energetically less costly.

4. Materials and Methods

4.1 Subjects and Housing

Testing included all birds that had completed a valid trial at least by the second session of the Base Technique test and demonstrated a willingness to continue. Consequently, 11 out of 18 birds (6 males, 5 females, all adults) housed in the Goffin Lab Goldegg were tested for the Base Technique. For the unbalanced test, 10 of the 11 previous subjects, with the exception of one female, were tested (see Appendix 10.1). All cockatoos are captive-born and hand-raised. Located at the Goffin Lab Goldegg in St. Pölten, Austria, they are housed in a large, environ mentally and socially enriched aviary. This facility includes an indoor area measuring 45 m^2 with a height range of 3 to 6 meters, and an outdoor aviary spanning 200 m^2 with a height range of 3 to 4.5 meters. The indoor environment is climate-controlled, maintaining a minimum temperature of 17°C during winter, and operates on a 12-hour light/dark cycle. The parrots are provided with an ad libitum diet that includes raw and boiled seeds, boiled vegetables, fresh and dried fruits, and fresh water. Each bird can be identified by colored rings on their legs.

Birds participating in voluntary testing sessions are called by name into an indoor testing roo m where they are separated from the group by visual isolation to prevent social learning.

4.2 Experimental history

Over the years, numerous studies have been conducted with these Goffin's using the stick-tool-box setup in various variations, resulting in prior experience with the mechanics of the basic stick-type apparatuses for most birds (Auersperg et al., 2012, 2014, 2017, 2018; Beinhauer et al., 2019; Bobrowicz et al., 2021; Ibáñez de Aldecoa et al., 2023; Laumer et al., 2016, 2021). In addition, the apparatuses used in this study were the same as those used approximately 1 year earlier by Osuna-Mascaró et al. (2023) with minimal modifications. Therefore, we did not need an extended habituation period. Instead, we excluded birds that showed neophobia towards the box, especially our younger and inexperienced individuals, as well as those that showed a lack of motivation to participate (See Appendix 10.1).

Prior experience with weight was provided by the study conducted by P. J. Lambert et al. (2021), in which 16 out of the 18 birds participated. Additionally, in the weight transport study by Adelmant et al. (2024), six birds had extensive experience with objects of varying weights in varying transportation modes.

4.3 Ethics

Prior to testing, this study was approved by the Ethics and Animal Welfare Committee of the University of Veterinary Medicine Vienna (ETK-179/11/2022) in accordance with guidelines for good scientific practice and national legislation.

All animals were in possession of valid CITES certificates and were officially registered with the district's administrative animal welfare authority (Bezirkshauptmannschaft St. Pölten, Schmiedgasse 4–6, A-3100, St. Pölten, Austria). Their housing complied with the Austrian Federal Act on the Protection of Animals (Animal Protection Act—§24 Abs. 1 Z 1 and 2; §25 Abs. 3—TSchG, BGBl. I Nr. 118/2004 Art. 2). Since our experiments were non-invasive, appetitive, and solely based on behavioral observations, they were not categorized as animal experiments under the Austrian Animal Experiments Act (§2, Federal Law Gazette No. 501/1989).

4.4 Apparatus and objects

4.4.1 Base Technique test apparatus and tool

The box used in this study was adapted from Osuna-Mascaró et al. (2023), where it was referred to as a "single-tool" box. No changes were made to the original design. The box is constructed entirely of Plexiglas and has dimensions of 22.5 cm in height, 20 cm in width, and 20 cm in depth. It is completely transparent and contains an internal slide with a central stand for placing a reward. The front wall has two openings: a circular hole 2 cm in diameter positioned at the same height of 11.2 cm as the stand inside to facilitate retrieval with a stick tool, and a lower slit to collect the reward after it slides down the ramp (See *Figure 1*). The stick tool for the Base Technique test was made from wood and cut to a length of 17,5 cm to be the appropriate length for reaching the reward. Its diameter was 7mm and weighed 7 grams. It was marked by a thin black line at the very center for sole visual purposes of video coding to differentiate between left and right side of the stick (see *Figure 1*).

4.4.2 Unbalanced Test apparatus and tools

The box used in this study had the same overall dimensions as the Base Technique box. It was made of Plexiglas with a black tinted slide and lid, the rest completely transparent. A rectangular ramp measuring 3 cm × 1.5 cm with a thickness of 5 mm was attached to the back of the box to allow the reward to "float" more freely inside the box, making it more difficult for the birds to reach the reward than by simply sliding the stick up the ramp. Since the front wall was removable, we removed the previous wall and made 2 different front walls that could be interchanged by a sliding mechanism as needed. One front wall had a horizontal opening of 15cm length and 1cm width, one front wall had a vertical opening of 15cm length and 1cm width. Both walls had a lower slit as in the previous boxes for reward collection. Everything else was removed, including the membrane and the screws that held it in place (see *Figure 1*).

Two sticks were constructed from hollow but sturdy plastic tubes with a diameter of 6 mm and a length of 17.5 cm, the same length as the wooden stick of the Base Technique test. The plastic sticks were weighted with 12 grams of malleable lead inserted into the bottom third of each stick, which was then sealed with plastic caps at both ends. This was the maximum weight that could be placed in the bottom third of the sticks to ensure an unbalanced weight distribution. The total weight of the sticks was 17,5 grams.

17.5 grams corresponds to approximately 6.15% of the body weight when considering the mean body weight of all 10 subjects participating in the study (283.5 grams). Approximately 6% of body weight has been identified in object transport experiments by Adelmant et al. (2024) as sufficient to facilitate weight-based choice discrimination. We hypothesized that the physical properties of a 17.5 cm-long unbalanced stick, which must be held at its very end to complete the vertical trial, would result in increased effort due to the additional torque generated. This torque amplifies the handling challenge as the length of the stick enhances the moment arm, requiring greater force to control the object effectively.

The two sticks were identical in construction, with the only difference being their markings. One stick was marked with a thin black stripe, approximately 1 mm in width, at the heavier end, while the other was marked with a similar stripe at the lighter end. These markings were intended for visualization during later video coding and for the randomization process described below. Additionally, both sticks were marked with a thin black stripe at the midpoint, as in the Base Technique test, for consistency in visualization (see *Figure 1*).

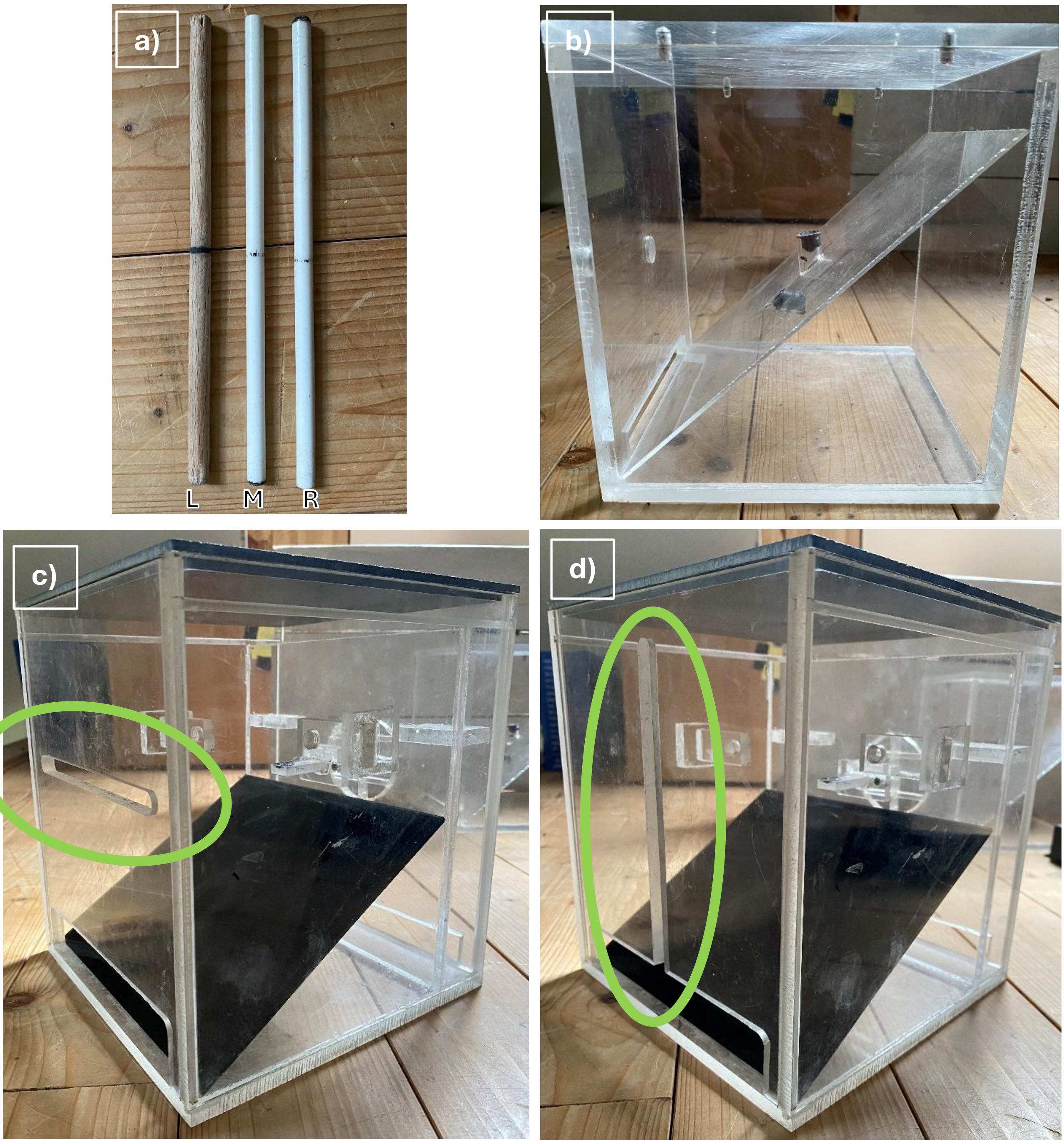

Figure 1**:** Apparatuses and tools used in the experiments. (a) Tools used in both experiments: Left (L): a light wooden stick, 17.5 cm in length, uniformly balanced, marked in the middle, and used for the Base Technique experiment with box (b). Middle (M) and Right (R): unbalanced sticks used in the unbalanced test (Box c) and d)) made from hollow, sturdy plastic tubes with a 12 g weight inside the lower third. Both sticks are physically identical except for the markings: (M) has the light side marked, and (R) has the heavy side marked. (b) Base Technique apparatus: a transparent Plexiglas box with a slide inside and a central stand for the reward, featuring two front openings: a central circular hole for tool insertion and a lower slit for reward retrieval. (c) and (d): Apparatuses for the unbalanced test: identical boxes differing only in the front window design, with (c) having a horizontal opening and (d) a vertical opening. Both apparatuses feature a reward stand mounted on the back wall and a black Plexiglas slide inside, designed to facilitate the sliding of the reward down to the retrieval slit at the bottom.

4.5 Experimental procedure

4.5.1 Base Technique test

Determination of insertion technique

The subjects were given five sessions, each comprising 10 trials, utilizing the Base Technique apparatus and stick. All subjects were tested with a maximum of 1 Session per day.

Trial procedure: The subjects were positioned on the backrest of a chair, facing the box on a table at a distance of approximately 50 cm. The box was baited with a piece of cashew nut, the size of which was approximately ¼ of a small cashew nut or 1/8 of a large cashew nut. Subsequently, the stick was positioned in front of the box at a distance of approximately 5 cm. Each trial commenced with the birds in a sitting position and the issuance of the command "Los gehts" (Go!) (see *Figure 2*). During the experiment, the experimenter was positioned behind the bird to prevent signaling of visual cues, minimizing Clever Hans measures (Samhita & Gross, 2013).

A trial was deemed successful if the time between the first pickup of the stick and the successful pushing over of the nut was under 5 minutes. A trial was considered unsuccessful if it took the subject longer than 5 minutes, if the subject showed no interest in participating, or if the subject deliberately threw the stick off the table. Deliberate throwing was defined as the act of the bird picking up the stick, carrying it to the edge of the table, and intentionally throwing it off the table. Instances in which the stick 'accidentally' rolled off the table during handling were not considered as deliberate throwing.

4.5.2 Unbalaced test

Determination of reaction to an unbalanced stick

Ten subjects were randomly assigned to two groups with 5 subjects each, with sex distribution being controlled for between groups. One group began with the vertical opening condition (Group VH), while the other started with the horizontal opening condition (Group HV) (Group distribution see *Table 1*). Each group completed 10 sessions, each consisting of 10 trials for the respective opening condition. Following this, the groups switched conditions and underwent the alternate opening condition, with 10 sessions and 10 trials per session, using the Unbalanced Test apparatus and stick. All subjects were tested with a maximum of one session per day, with the exception of Heidi, who was tested twice a day starting after Session 6 of the first condition (vertical opening) (see Appendix 10.1).

Trial procedure: Similar to the Base Technique test, subjects were positioned on the edge of a chair, facing the box on a table at a distance of approximately 50 cm. The box was baited with a piece of cashew nut, approximately ¼ of a small cashew nut or 1/8 of a large cashew nut in size. The sticks were placed approx. 5cm in front of the box, as in the Base Technique, but in a randomized manner throughout the trials. Prior randomization determined which stick was used (either the heavy side marked stick or the light side marked stick) and the placement of the marking (right or left side). This randomization was implemented to eliminate learning effects and side biases, whether intrinsic (subjects having a preferred side) or triggered by the marking. Each trial commenced with the birds in a sitting position and the issuance of the command "Los gehts" (Go!) (see *Figure 2*). During the experiment, the experimenter was positioned behind the bird.

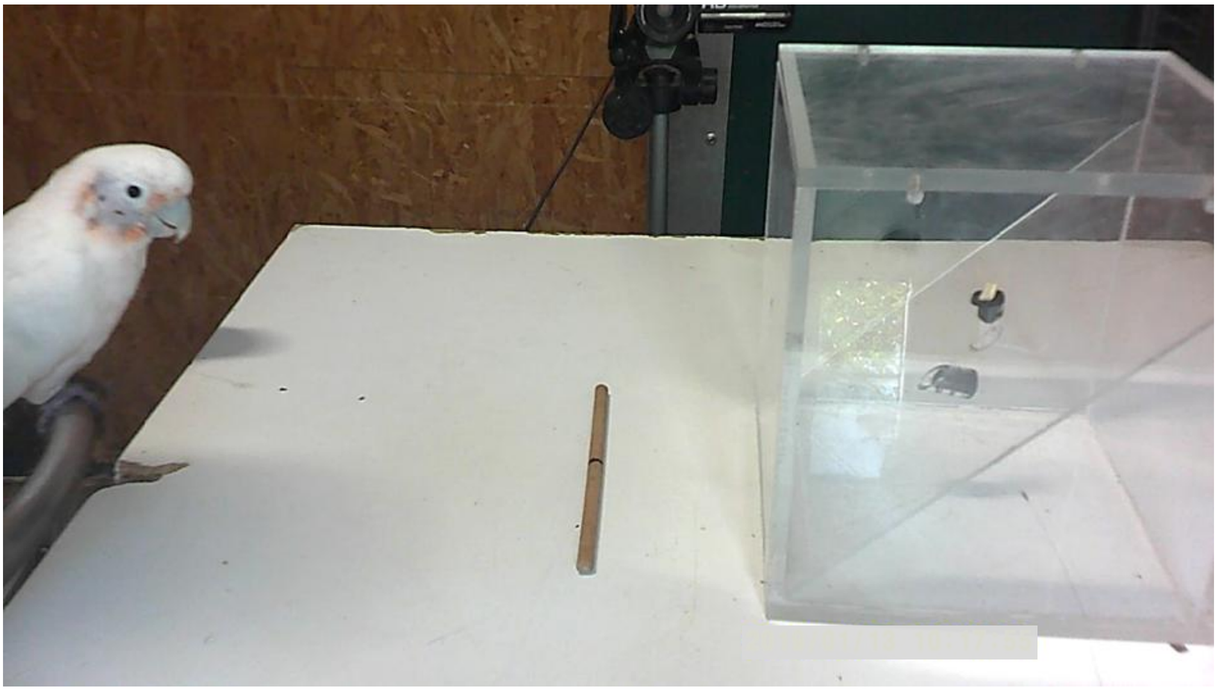

Figure 2: Side-on view of the experimental setup and trial procedure (illustrated with the Base Technique Test, but identical for the Unbalanced Test): The subject is positioned on the edge of a chairback approximately 1-2 cm away from the experiment table. The box is baited with a piece of cashew, and the respective tool is placed about 5 cm in front of the box, parallel to it. The subject (here, Muppet) is allowed to observe the baiting of the box and the placement of the tool but can only begin the task following the 'los geht's' command. The trial begins when the subject picks up the tool and finishes when the reward is pushed over.

A trial was deemed successful if the time between the first pickup of the stick and the successful pushing over of the nut was under 5 minutes. A trial was considered unsuccessful if it took the subject longer than 5 minutes, if the subject showed no interest in participating, or if the subject deliberately threw the stick off the table. Deliberate throwing was defined as the act of the bird picking up the stick, carrying it to the edge of the table, and intentionally throwing it off the table. Instances in which the stick 'accidentally' rolled off the table during handling were not considered as deliberate throwing.

4.6 Video recording

Two IR FHD 1080p High-Definition Video Camera Camcorders with the model number 3051LRM were used to record all trials during both experiments. The cameras were positioned on opposite sides of the table, providing a side-on view of the apparatus and tool. This setup ensured that two angles were captured, allowing for comprehensive observation of the stick movements. This was particularly useful in cases where one angle might be insufficient due to obstructions, such as when the subjects head or beak was turned away from the camera, obscuring the view.

4.7 Statistical analyses

We conducted a linear mixed-effects analysis to evaluate differences in the effectiveness of technique groups for the Base Technique test, specifically focusing on their completion durations. The analysis involved log-transformed trial times as the dependent variable. The model included fixed effects for *TechniqueGroup* and *Session*, as well as random effects for *Subject*, with a random intercept and a random slope for *Session.* Model overview, Model stability and output See Appendix 10.2.

To determine whether birds were more likely to complete the unbalanced test with the light side (LS) of the stick inserted, we performed a generalized linear mixed-effects model (GLMM). The dependent variable, *CompletionWeight* (LS or HS completions), was modeled with *ConditionSlit* as the primary predictor and *Session*, *ToolPosition*, *Weight*, *Group*, and *Technique* as control predictors. To account for pseudoreplication and repeated measures from the same individuals (including multiple measurements within a single day), we included *Subject* and *Subject.Date* as random intercept effects. Model overwiev, model stability and output see Appendix 10.2.

All statistical analyses and graphs were conducted and constructed using R version 2023.12.1.402 (R development Core Team, 2024) and packages: lme4 (version 1.1-30, Bates et al., 2015), car (version 3.1-2, Fox & Weisberg, 2019), dplyr (version 1.1.4, Wickham et al., 2023), tidyr (version 1.3.1, Wickham et al., 2024), tidyverse (version 2.0.0, Wickham et al., 2019), ggplot2 (version 3.4.1, Wickham, 2016), forcats (version 1.0.0, Wickham, 2023).

5. Results

5.1 Base Technique test: Individual techniques

Here, we describe only the insertion techniques up until the point at which the stick is fully inserted. The tool movements inside the box were of no interest for this study as they are similar in all subjects and do not seem to follow a distinct pattern. Subjects were grouped together if they showed the same distinct pattern category in their insertion technique (with minor deviations) and were given titles (in cursive) for further simplification. It is noteworthy that all birds had established their respective techniques by the conclusion of the first session, with 10 out of 11 subjects demonstrating at least two consecutive trials of employing a consistent technique. By the second session, all subjects, with the exception of Olympia—who exhibited four consecutive trials—demonstrated a minimum of 10 consecutive trials utilizing the same technique. This suggests that subjects had developed and implemented their baseline technique by the second session at the latest. No significant deviations from these individual techniques were observed until the conclusion of the fifth session. Reference videos of all individual techniques see Appendix 10.6.

<u>Figaro</u>
Figaro's technique

The insertion technique employed by Figaro was markedly distinct from those observed in other subjects, as he exclusively utilized his beak throughout the entire insertion process and was also the only one using a 'precision-grip' where the tool is held firmly between the tip of his muscular tongue and the tip of the upper mandible (See *Image 1*) .

Image 1) Left: Side view of the grip of the Goffin's cockatoo between the upper and lower mandibles. Right: Side view of the 'precision grip,' where the stick tool is held between the muscular tongue and the tip of the upper mandible. (Images provided by Alice Auersperg).

He is the most experienced, oldest, and highest-ranking member of the flock. Previous experiments have demonstrated that his technique is highly refined and internalized (Auersperg et al., 2012, 2014; Osuna-Mascaró et al., 2022). Figaro grasps the stick at one end between his upper and lower mandibles, then steps back the appropriate distance from the box. He then adjusts the stick in his beak so that the very end is held either between his upper and lower mandibles or between his tongue and upper mandible. From this position, he inserts the stick, occasionally adjusting the front tip to align with the hole entrance and fully inserting it in one motion. Contrary to our expectations from previous observations (Auersperg et al., 2012, 2014; Osuna-Mascaró et al., 2022), he more frequently used grasping the stick between his mandibles than grasping it between his upper mandible and tongue (see *Figure 3*). This outcome may be due to the stick being significantly longer and heavier than the tools previously used for this gripping technique, reducing its precision and rendering it ineffective. Furthermore, in some instances, distinguishing between the two gripping techniques was challenging (categorized as NA in *Figure 3*) because the cameras used did not provide sufficiently high-resolution images to capture detailed beak and internal movements.

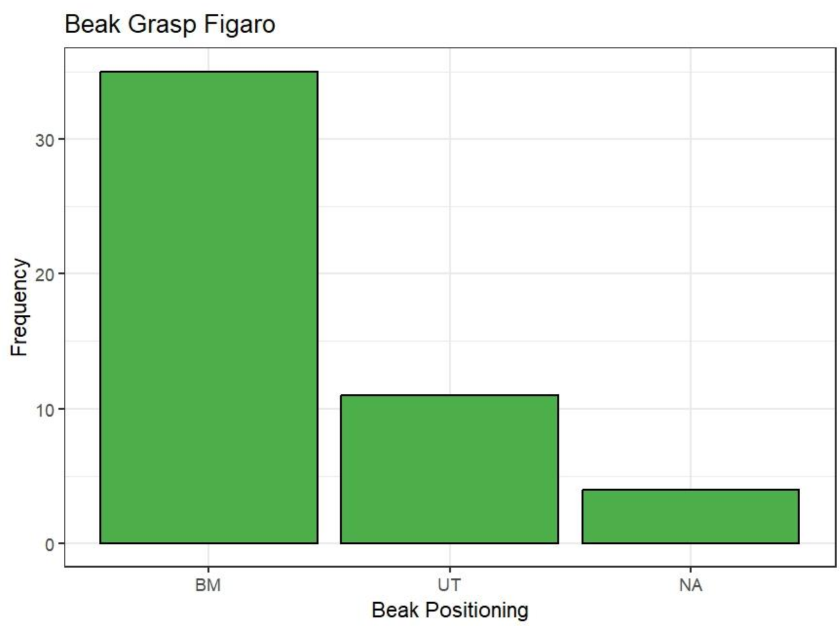

Figure 3 Frequencies (Number of times a trial was completed with either grip) of Figaros grasping techniques throughout the Base Technique experiment: BM (Between mandibles), UT (Between Upper Mandible and tongue), NA (No data or Technique undifferentiable).

<u>Fini, Mayday and Kiwi</u>
The needling technique

These subjects picked up one end of the stick with their beaks and, by stepping closer to the box, moved that proximal end close to the entrance hole while turning their heads sideways. Mayday first inserted a small portion of the proximal end, held between her mandibles (approximately 5 mm), into the hole. She then proceeded to push the stick further using her tongue, making repeated thrusts while the stick remained secure through the opening and held loosely between her mandibles. Fini and Kiwi, after bringing the proximal end close to the entrance, immediately began needling the stick into the box. They held the stick loosely between their mandibles while using their tongues to thrust the stick bit by bit into the box until it was approximately halfway in. Once the stick was inserted to about the halfway point and securely positioned within the box (such that it could not fall out), all subjects released the beak grip and moved back to the distal end of the stick. From this position, they grasped the distal end relative to the box between their mandibles and, with a single push, completed the insertion (See *Image 2*). This technique was previously documented in a separate experiment involving Fini (Osuna-Mascaró et al., 2022) but was systematically recorded in Kiwi and Mayday for the first time in this experiment.

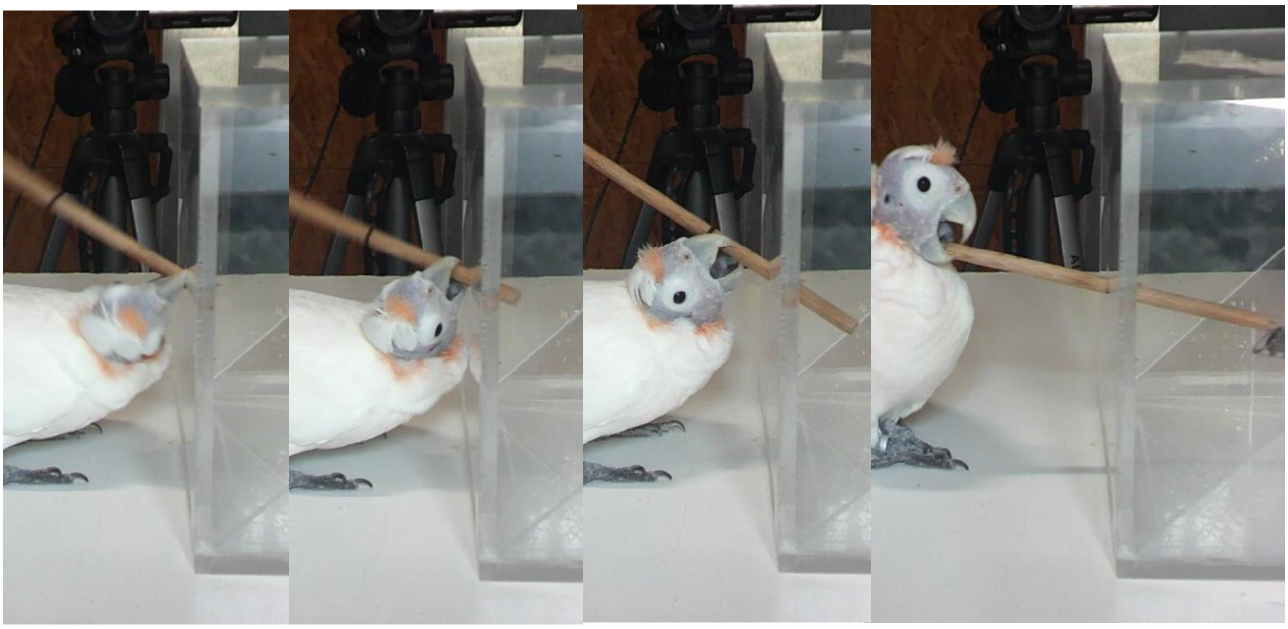

Image 2) Sequential snapshots illustrating the needling technique, as demonstrated by Fini. After picking up one end of the stick with her beak, Fini moved the proximal end closer to the opening. By holding the stick loosely between her mandibles, she repeatedly pushed it further into the box using tongue thrusts. Once the stick was approximately halfway inserted, Fini stepped back to the distal end and completed the insertion with a single push using her beak.

<u>Zozo, Heidi, Pipin and Olympia</u>

Foot insertion

These subjects employed a distinct method of tool use in which they grasped one end of the stick with their beaks and positioned it near the entrance hole, holding it proximally. From this position, Heidi, Pipin, and Olympia grasped the stick with one foot approximately in the middle, while Zozo grasped it just behind the proximal end. Using their feet, they pushed the stick into the box, with a minimum of one-quarter of the stick's length inserted. This technique set itself apart from the others as the insertion push was executed with the foot rather than the beak or tongue in the aforementioned techniques. The choice of foot varied among the subjects, suggesting a tendency towards left or right foot dominance. The subjects began by inserting the tip of the stick with a foot push while simultaneously moving their heads to the distal end of the stick. Zozo and Heidi then grasped the stick near its distal end between their mandibles, released the foot hold, and completed the insertion in a single fluid motion using a beak push (stick held between mandibles) (see *Image 3*). In contrast, Pipin and Olympia loosely grasped the stick with their beaks alongside the foot hold, released the foot hold, and used tongue thrusts (or needling) to glide the stick into the box. Once the stick was securely positioned inside the box, they finalized the insertion with a beak push. Notably, Pipin and Olympia were the only subjects to combine foot, tongue, and beak pushes in their techniques. Pipin was previously observed using this technique in the composite tool experiment (Osuna-Mascaró et al., 2022). However, this marks the first systematically recorded instance of Olympia, Zozo, and Heidi employing this method.

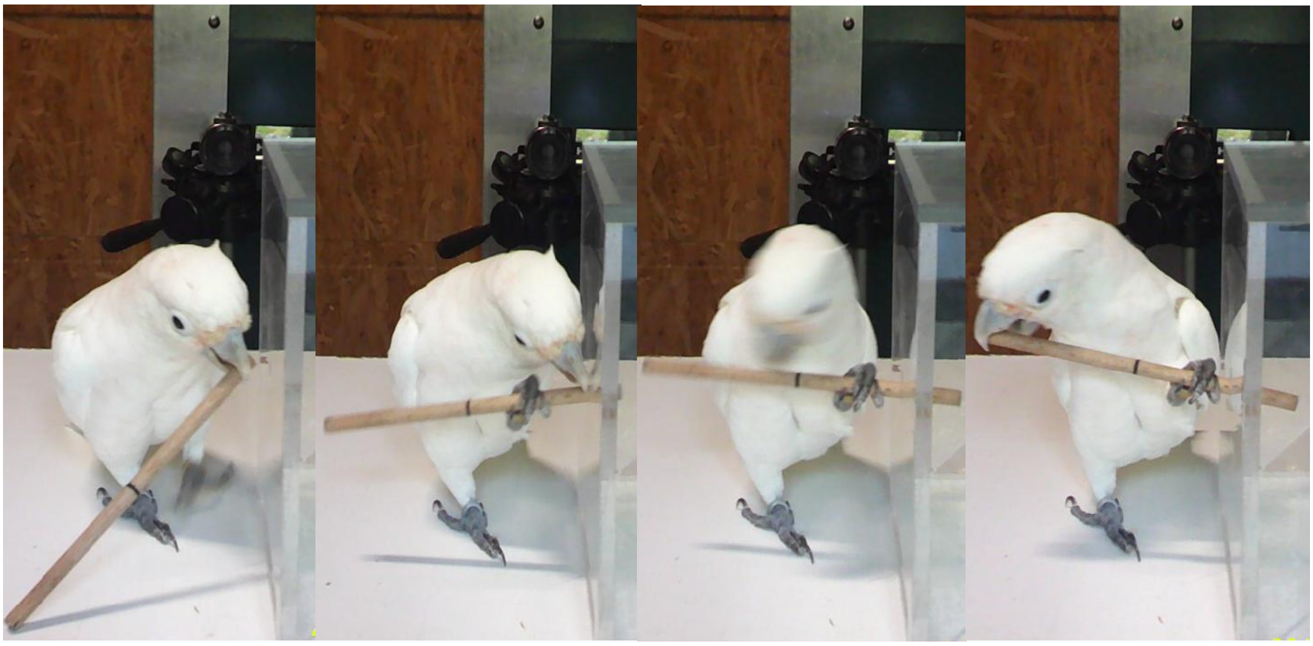

Image 3) Sequential snapshots illustrating the foot insertion technique, as demonstrated by Zozo: After picking up one end of the stick with his beak, Zozo moved the proximal end closer to the opening. He then secured the stick near his beak grip with his foot. While pushing the stick approximately 1–2 cm into the box using his foot, he simultaneously shifted his head to the distal end of the stick and grasped it with his beak. Once the distal beak grip was established, Zozo released the foot hold and completed the insertion in a single motion using his beak.

Muppet, Moneypenny and Dolittle

Entrance securing

All three subjects' techniques began with picking up one end of the stick and, as described before, moving the proximal end to the entrance. They secured the proximal end of the stick at the box opening using their beaks and/or tongues, leveraging the stick and utilizing the physical properties of the setup. The proximal end rested at the entrance, while the distal end was supported by the ground, positioning the stick at approximately a 45° angle. This method ensured the stick remained stable, allowing the subjects to either release it completely or step away without disturbing its position. Moneypenny secured the stick at the entrance while holding it between the mandibles, then stepped back and picked up the distal end to push it into the box in a single motion. Muppet secured the stick using his beak and foot, then glided down its length with his beak until reaching the distal end, where he completed the insertion in a single motion. Dolittle, after securing the stick's end with his beak and tongue, glided down the stick with his beak until he was approximately 1–2 cm from the distal end. He then grasped the stick with his beak, pushed it about two-thirds of the way into the box in one motion, adjusted his beak grip to the very end of the stick, and completed the insertion with one final push. Notably, although both Dolittle and Muppet could technically step away entirely from the stick, as Moneypenny did, they appeared to prefer maintaining control by keeping continuous contact with the stick as they guided it down.

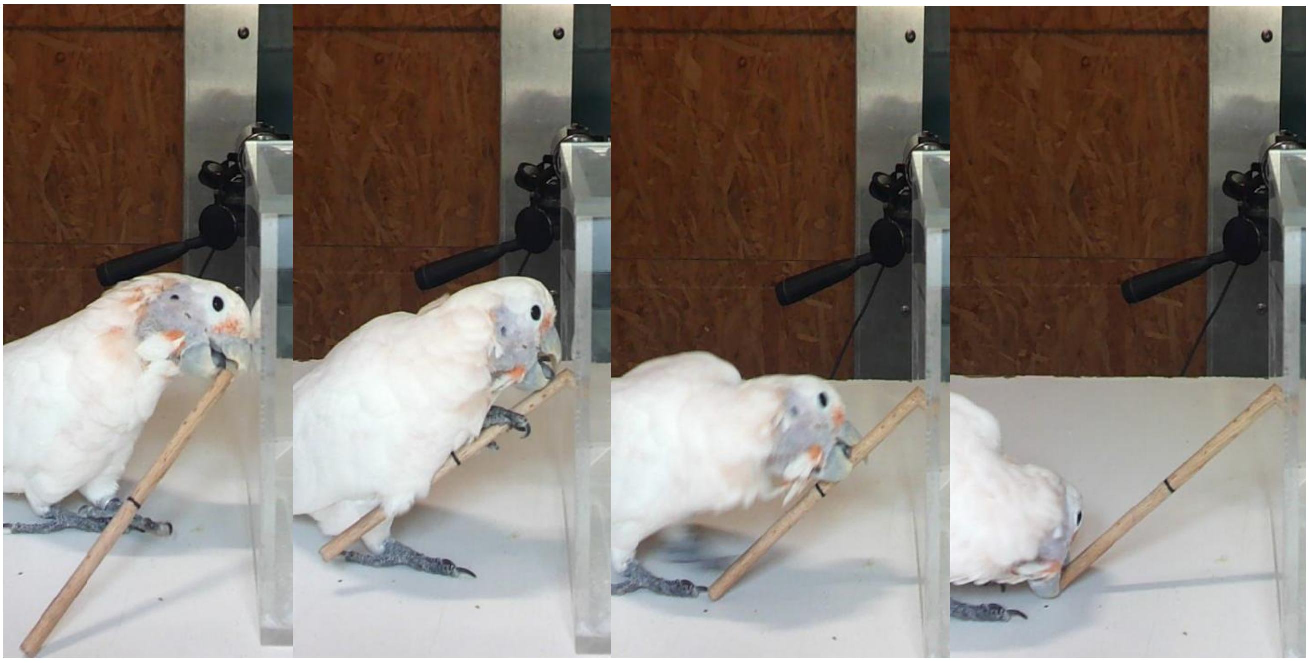

Image 4) Sequential snapshots illustrating the foot insertion technique, as demonstrated by Muppet: After picking up one end of the stick between the mandibles and bringing it close to the entrance, Muppet stabilized the proximal end at the opening using his beak and foot. Once the stick was secured and rested at the entrance, he guided it down using his beak, grasped the distal end between his mandibles, and completed the insertion with a final push using his beak.

Model output Base Technique test

Trial time overall + Trial time when grouped into the techniques

The mean trial time for successful trials between the subjects varied between 8.24 and 32.5 seconds (see Appendix 10.4). The model summary revealed significant fixed effects of session on trial times (estimate: -0.257 +- 0.027; $F(1, 9.55) = 89.72$, $p < 0.001$), indicating that trial times significantly varied across sessions suggesting learning behaviour. However, there was no significant effect of Technique group ($F(3, 6.95) = 2.64$, $p = 0.131$) on trial times (see *Figure 4*).

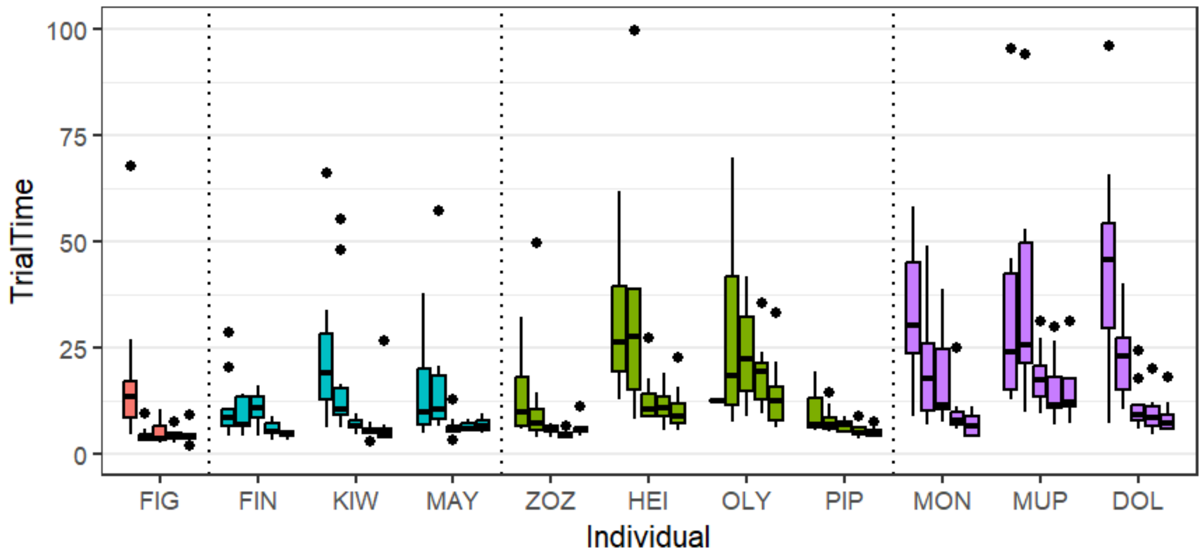

Figure 4 Plots visualizing the mean time (in seconds) of successfully finished trials per session per subject. Subjects grouped together by technique, shown here in colors (Red=*Figaro's Technique*, Blue= *Needling*, Green=*Foot Insertion*, Purple= *Entrance Securing*). No significant differences between the groups were detected.

5.2 Unbalanced test: Individual Techniques and changes

5 out of 10 subjects changed their technique at least once when confronted with either the horizontal opening and/or the vertical opening. In the following the detailed changes and adaptations or the lack thereof by each individual will be explained. Reference videos for all subjects see Appendix 10.7.

Technique changes:

Group HV: Beginning with horizontal opening

Figaro:

Throughout all 20 sessions, Figaro consistently maintained his previously established technique from the Base Technique test. For detailed description of Figaro's reactions during the course of the experiment see Appendix 10.6.

Unlike in the Base Technique test, he did not utilize the previously observed UT beak grip (or precision grip). This was likely because the unbalanced stick was too heavy to allow for the precision that this technique typically affords with shorter and lighter sticks.

Fini:

Fini's technique remained consistent from the Base Technique test to the Unbalanced test for all 20 Sessions. For detailed description of Fini's reactions during the course of the experiment see Appendix 10.6.

Mayday:

In the horizontal condition, Mayday did not deviate from her previously established baseline technique. Although encountering difficulty in the following vertical condition, she successfully completed 20 trials using her baseline technique. For detailed descriptions of Mayday's reactions during the course of the experiment, see the Appendix 10.6.

The limited data in Maydays data set posed challenges for including her into the statistical analysis (see Appendix 10.2).

Dolittle:

In the horizontal condition, his initial attempt to insert the stick into the box involved using his established securing method from the Base Technique test. However, this attempt was unsuccessful as the stick immediately fell out due to the lack of lateral support at the entrance. He quickly adapted by transitioning to a needling approach, successfully inserting the stick by his third try. This new technique closely resembled the *Needling* method employed by Mayday, Fini, and Kiwi during the Base Technique test. This response demonstrated immediate flexibility when facing a novel challenge. Although he did not complete any successful trials in the first session, likely due to difficulties in determining how to manipulate the stick to push the nut once inserted, he began to achieve successful consecutive trials from session 2 onward, consistently applying the new *Needling technique*. Ultimately, he successfully completed 89 out of 100 trials in the horizontal condition.

In the vertical condition, his first approach involved inserting the stick using the needling technique and then attempting to push the inserted end up the ramp. However, because of the gap between the ramp and the platform holding the nut, he seemingly failed to recognize that the stick needed to be lifted to reach the nut, unlike in the previous boxes where sliding motions sufficed. During sessions 1 to 3, his attempts primarily involved inserting the stick with the needling technique; however, it wasn't until session 4 that he began to become consistently successful, suggesting improved control of the stick through a learning effect. He successfully completed 59 out of 100 trials in the vertical condition, with frequent switching behavior of stick ends observed throughout.

<u>Zozo:</u>

Zozo did not deviate from his previously established foot insertion technique in both the horizontal and vertical condition. For detailed description of Zozo's reactions during the course of the experiment, see the Appendix 10.6.

<u>Group VH: Beginning with vertical Slit</u>

<u>Kiwi:</u>

In the initial trial of the vertical condition, Kiwi exhibited no hesitation in employing his established needling technique to swiftly insert the stick into the box. During attempts to maneuver the stick to push the bait, it fell out several times; however, he adeptly reinserted it without difficulty. Notably, in the final successful insertion that resulted in pushing the bait, Kiwi unexpectedly grasped the stick by its distal end and inserted it entirely in this manner, mirroring *Figaro's technique*.

Throughout the subsequent trials of the first session, he demonstrated flexibility by alternating between the needling technique and Figaro's method. Although the switching between techniques appeared initially arbitrary, both methods yielded comparable success rates in pushing the bait. Over the course of 10 sessions, during which all 100 trials were completed successfully, Kiwi consistently alternated between these two techniques.

For the horizontal condition, insertion behavior was as consistent and efficient as in the vertical condition. He did not faithfully revert back to his baseline technique but alternated between stick insertion using Figaro's technique and his baseline technique, completing the first and all consecutive 100 trials successfully. He demonstrated flexibility by alternating between techniques as in the previous condition.

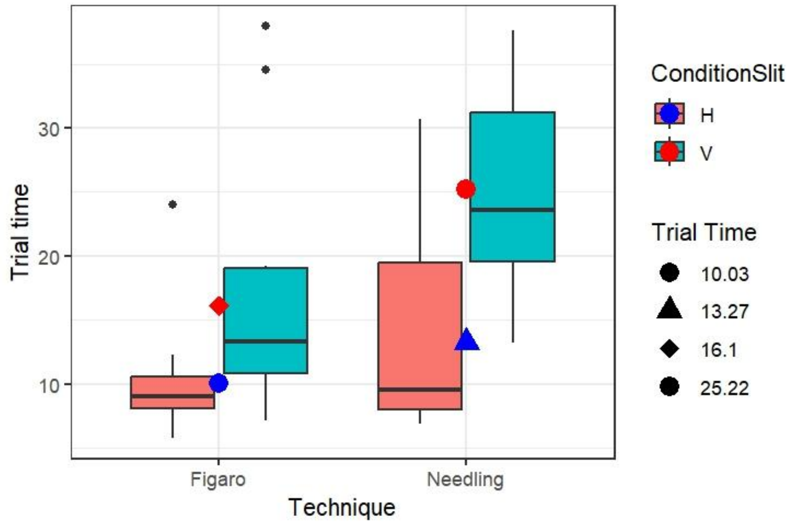

Figure 5 Boxplots with respective mean trial times in seconds for each opening condition and techniques used by Kiwi.

The mean trial time for each opening condition using both techniques was plotted, highlighting the effect of each technique on trial time (see *Figure 5*). When Figaro's technique was used in the vertical condition, it resulted in approximately 36% faster trial times compared to the needling technique. In contrast, the horizontal condition showed only a minor difference in mean trial time between the two techniques.

<u>Heidi:</u>

Heidi did not deviate from her previously established foot insertion technique in both the horizontal and vertical condition. For detailed description of Heidi's reactions during the course of the experiment, see the Appendix 10.6.

<u>Moneypenny:</u>

In the first trial of the vertical condition, she displayed no hesitation in picking up the stick by its end and stepping back approximately the stick's length before inserting it fully with the distal end first—closely resembling *Figaro's technique*. This demonstrated a quick and adaptable response, as she bypassed her previous securing method, which likely would not have been effective due to the lack of leverage support from the box. Although she lost control of the stick a few times, she repeatedly picked it up and reinserted it as before, ultimately completing the trial successfully within five minutes.

In the second trial, however, she encountered difficulty inserting the stick. She initially attempted Figaro's technique, with some deviations, such as the additional use of foot holds, but was unable to complete any of the insertions successfully. After approximately 200 seconds of repeated attempts, she deliberately discarded the stick, ending the session without success.

From Session 3 onward, she successfully completed the trials using Figaro's Technique and applied this technique in all subsequent trials without deviation. Overall, she successfully completed 81 out of 100 trials in the vertical condition.

Her technique differed slightly from Figaro's in terms of her positioning in front of the box. She held the stick by its very end, keeping it relatively vertical without contacting other surfaces, then stepped closer and raised it to approximately a 90-degree angle within the vertical slit, allowing the distal end to enter the box. In contrast, Figaro lifted the stick to a 90-degree angle prior to insertion and then inserted it horizontally along its length. Nonetheless, both Moneypenny and Figaro held and maneuvered the stick entirely by its end, with the leverage point resting solely in their beaks throughout the process.

In the first trial of the horizontal condition, she promptly picked up the stick to insert it as she had in the vertical condition—a technique resembling Figaro's. However, this approach was unsuccessful, as the horizontal slit did not permit the 90-degree lift she used in the vertical slit, leading her to fail repeatedly and drop the stick several times. After approximately 130 seconds, she seemingly grew frustrated, deliberately discarded the stick, and abandoned the session as unsuccessful. This pattern persisted for the next seven sessions: she consistently attempted to insert the stick using Figaro's technique but remained unsuccessful.

It was not until Session 9 that she achieved her first successful trial. After a few initial attempts, she succeeded by holding the stick near its midpoint with her foot and adjusting it so that her beak grasped the distal end. The proximal end of the stick then aligned with the slit entrance, and she pushed the stick into the box in one motion with her beak. In the second trial, she repeated this new method, which resembled a combination of the securing method and foot insertion. She held the stick in the middle, grasped it distally between her mandibles, and slid the proximal end along the box wall from top to bottom until it reached the slit, then inserted it in a single beak-pushing motion. She used this technique consistently for all subsequent trials, ultimately completing 20 out of 100 trials successfully. With this shift, she became the only subject to establish a new technique more than once—more specifically, adapting a distinct technique for each of the baseline, vertical, and horizontal conditions.

In particular, she showed remarkable adaptability in the vertical condition, successfully developing an entirely new method of insertion for what appeared to be a more difficult task. However, she encountered significant difficulties in the horizontal condition. Her newly established Figaro-like technique could probably have been successful if she had adapted it to lift the stick to a 90 degree angle prior to insertion, as Figaro and Kiwi had done. Similarly, her baseline securing technique might have been effective if she had taken into account the lack of lateral support. Instead, she deviated from these approaches and opted for a completely different strategy.

<u>Pipin:</u>

In the first trial of the vertical condition, Pipin showed minimal hesitation, picking up the stick and attempting to insert it into the box using his baseline technique, foot insertion. Although foot insertion itself was successful for the first 3 sessions, he did not manage to push over the bait, eventually leading to the termination of the trials through deliberate throwing of the stick by Pipin.

From session 4 onward, he began achieving consecutive successful trials with the previously established foot insertion technique. In session 7, trial 4, an unexpected behavior occurred: after picking up the stick, he suddenly used a technique very similar to *Figaro's Technique* and successfully pushed over the bait on the first try. This was notable as he had been consistently succeeding with the foot insertion technique up to this point. Following this, he displayed flexible switching behavior between the two techniques, similar to Kiwi, completing all subsequent trials successfully with either method.

In the first trial of the horizontal condition, he picked up the stick without hesitation and attempted to insert it using Figaro’s Technique, but was unsuccessful. He then tried the foot insertion method, his baseline technique, which succeeded; however, he experienced difficulty maneuvering the stick within the box to push over the bait, likely due to the greater lateral movement range in the horizontal slit compared to the vertical one. After approximately 230 seconds, he terminated the trial and ended the session by discarding the stick.

In session 2, trial 1, he successfully completed the trial using the foot insertion technique. From that point onward, he consistently used this technique to complete all subsequent trials, achieving success in 90 out of 100 trials within the horizontal condition. Notably, he was the only subject to revert to his baseline technique after previously utilizing a new technique in the vertical condition.

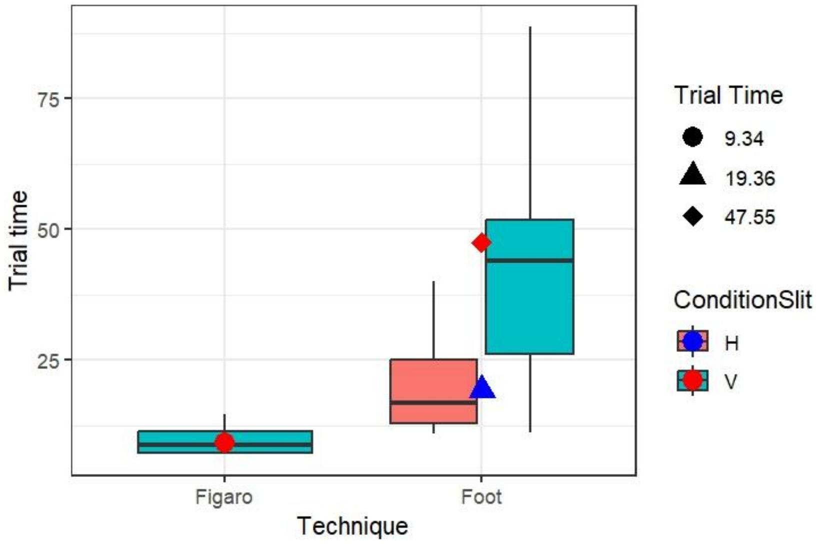

Figure 6 Boxplots with respective mean trial times in seconds for each opening condition and techniques used by Pipin.

The mean trial time for each opening condition using both techniques was plotted, highlighting the effect of each technique on trial time (see *Figure 6*). When Figaro's technique was used in the vertical condition, it resulted in approximately 80% faster trial times compared to the foot insertion technique.

<u>Muppet:</u>

When first confronted with the vertical slit in Session 1, Trial 1, he exhibited greater hesitation toward the stick and box than other subjects. He attempted to pick up the stick twice, then let it fall, returned to his chair, and remained stationary, showing minimal motivation to continue. In the second trial, he displayed a similar pattern, interacting briefly with the stick but eventually losing interest in further exploration, resulting in an unsuccessful session.

In Session 2, he exhibited reduced hesitation, picking up the stick by its end with his beak, moving closer to the box, and then securing the middle of the stick with his foot. He adjusted the stick's end at the slit entrance using his beak, initiating insertion by pushing 1–2 cm with his foot. He continued by grasping the stick near his foot with his beak, repositioning his foot along the stick, and pushing it further into the slit, alternating between foot and beak. This sequence resulted in a gradual insertion, with the initial push executed by his foot. This technique, resembling the *Foot insertion* approach observed in other subjects, marked a novel approach from his previously established entrance securing technique. His first attempt was unsuccessful as the stick fell out; however, he reattempted and managed to insert the stick fully, though he did not push the nut over. Losing further interest, he abandoned the trial.

By Session 3, he began achieving consecutive successful trials with this newly established foot insertion technique. He ultimately completed 60 out of 100 trials successfully, consistently employing this newly developed technique.

In Session 1, Trial 1 of the horizontal condition, his initial attempts at insertion employed the previously established foot insertion technique of the vertical condition. Though not immediately successful and requiring several attempts, he ultimately completed the trial successfully. In all subsequent trials, except for two, he continued to use the foot insertion technique. In the two exceptions, the subject reverted to his baseline technique of entrance securing. It is hypothesized that this baseline technique was significantly more challenging due to the lack of lateral support provided by the horizontal opening. Nevertheless, he successfully completed all 100 trials in the horizontal condition.

Table 1 Summary and comparison of the subjects Baseline Techniques, Technique changes in each opening condition, chance of LS completion and side preferences (stick side of the first pickup) in the unbalanced test. (*) indicates insufficient data for significance testing.

Subject	**Baseline Technique**	**Group**	**Technique Change in condition**		**Chance of LS completion over 50 percent**		**Side preference**
			horizontal	vertical	horizontal	vertical	
Figaro	Figaro's	HV	no	no	no	no	none
Fini	Needling	HV	no	no	no	**yes**	right
Mayday	Needling	HV	no	no	no	no*	left
Dolittle	Securing	HV	**yes**	**yes**	**yes**	**yes**	right
Zozo	Foot	HV	no	no	**yes**	**yes**	left
Kiwi	Needling	VH	**yes**	**yes**	no	no	right
Heidi	Foot	VH	no	no	no	**yes**	right
Moneypenny	Securing	VH	**yes**	**yes**	no	no	none
Pipin	Foot	VH	no	**yes**	no	**yes**	left
Muppet	Securing	VH	**yes**	**yes**	no	**yes**	left

All birds except Heidi showed a significant increase of mean trial time from the Base Technique test to the Unbalanced test (See Appendix 10.4).

5.3 Unbalanced test: weight preference

The model summary revealed significant fixed effects of opening condition (V/H) on successfully completed trials with the light-end of the stick (H=0.485+-0.07, V=0.885+-0.05; $\chi^2_{(1)} = 8.07$, $p < 0.01$) (see *Figure 8*). Six out of ten birds displayed a significant preference for completing trials with the light side inserted during at least one of the two conditions across all successful trials. Additionally, two birds showed a significant preference for LS completion in both opening conditions. Notably, one subject, Kiwi, exhibited a significant preference for heavy-side completion in the horizontal condition (see *Figure 8*). Importantly, there was no significant correlation between LS completion probability and subject weight (see *Figure 9*).

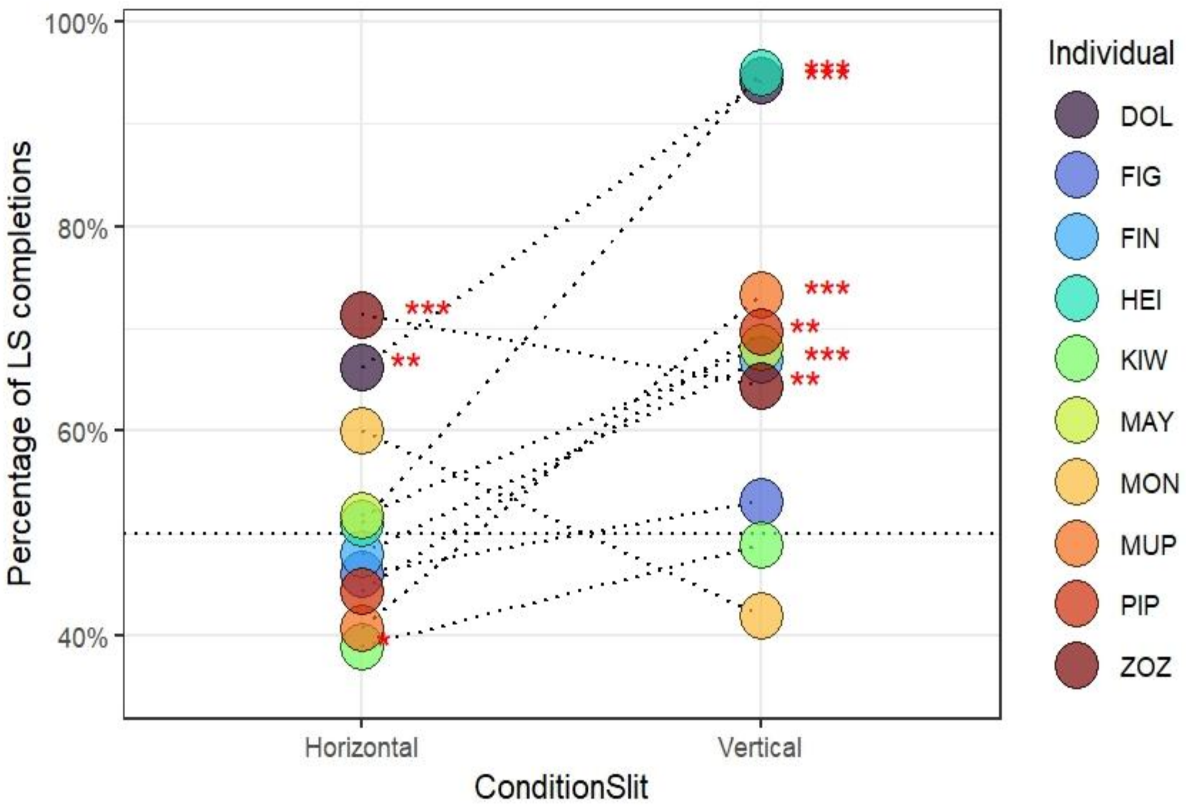

Figure 8 Plot showing the percentage of light side completions (LS) for each subjects for the two conditions horizontal (H) and vertical (V). Dashed line at 50% marks the expected level of LS-completions if choice were random. Significance levels from a binomial test comparing observed insertions to an expected 50% rate are labeled directly above each data point (with *, **, or *** indicating statistical significance at different thresholds).

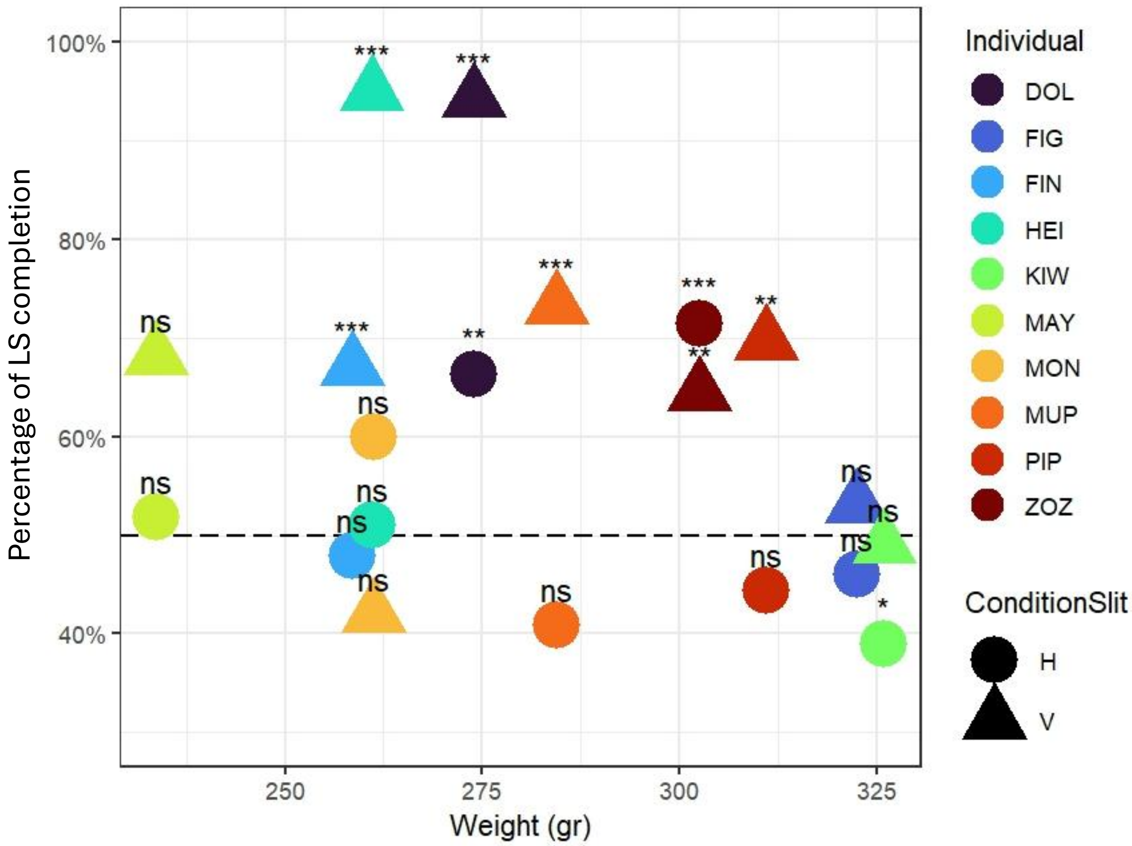

Figure 9 Plot showing the percentage of light side completion (LS) for each subject sorted by their weight for the two conditions horizontal (H) and vertical (V). Dashed line at 50% marks the expected level of LS-completions if choice were random. Significance levels from a binomial test comparing observed insertions to an expected 50% rate are labeled directly above each data point (with *, **, or *** indicating statistical significance at different thresholds, while "ns" denotes non-significance).

All birds except Figaro and Mayday showed either a technique change or LS completion above chance level in the Unbalaced Test. 3 birds showed both (Muppet, Dolittle, Pipin) (see *Table 1*).

6. Discussion

Our findings partly confirm Prediction 1, indicating that when presented with a more complex box and tool setup, Goffin's cockatoos flexibly adapt their previously established, individual-specific techniques. Additionally, Prediction 2, which predicted the Goffin's preference for inserting the unbalanced stick with the lighter end, was supported. A significant group-level effect was observed in the vertical condition, with trials completed using the lighter end inserted exceeding the 50% chance level. This finding demonstrates that

Goffin's can not only assess weight differences of otherwise identical objects and apply weight cues for transport decisions (Adelmant et al., 2024; P. J. Lambert et al., 2021) but can also assess and respond to unproportional weight distribution in a functional tool.

Prediction 1 was only partially supported, as five out of ten birds altered their technique when transitioning from the baseline to the unbalanced condition. Notably, four of these five individuals also modified their technique in the horizontal condition, in addition to the vertical condition. This could suggest that the horizontal condition, due to the lack in lateral support, was more challenging to adapt to than initially anticipated.

All birds that had established the entrance securing technique as their baseline were compelled to adapt in both new conditions, as the openings no longer provided sufficient leverage. Consequently, all subjects developed new techniques. While Muppet and Dolittle, upon discovering a solution in the first condition, simply carried this technique over into the subsequent condition, Moneypenny responded to each novel challenge by developing a distinct new solution. This pattern aligns with the findings of Manrique et al., (2013), who demonstrated that apes faced with a puzzle box requiring increasingly complex solving strategies efficiently abandoned prior methods once they became unviable. Similarly, it reflects the observations of Auersperg et al. (2011), which showed that Kea and New Caledonian crows in a multi-access box experiment readily switched to novel solutions when their previous strategies were obstructed. This behavior suggests a high degree of behavioral flexibility and inhibitory control. This does not necessarily imply that Moneypenny exhibits a higher rate of innovation compared to the other birds. Instead, her multiple adaptations may simply reflect the fact that her previous solutions were incompatible with the new challenges, whereas the other birds' existing solutions happened to be effective in addressing the novel conditions.

More intriguing is the occurrence of technique changes in situations where they were not strictly "necessary"—that is, when a new technique was innovated despite the previous method working consistently. Such spontaneous switching, not driven by necessity, was observed in Kiwi and Pipin.

Both birds alternated freely between their baseline techniques and Figaro's technique in the vertical condition, with comparable success rates in completing trials for both methods. However, trial duration analysis revealed that using Figaro's technique was faster and thus more effective for both birds. This observation is particularly intriguing, as in previous experiments, both birds had been exposed to Figaro as a demonstrator but did not imitate his technique at the time (Auersperg et al., 2014).

Since social learning and random exploration reinforced by trial and error can be ruled out in this case, we propose that cognitive flexibility (Audet & Lefebvre, 2017; Manrique et al., 2013; Sol et al., 2005; Tello-Ramos et al., 2019) may underlie the observed technique switches in these birds. The spontaneous adoption of Figaro's technique likely represents an adaptive behavior, where individuals identified and implemented a novel method perceived as more efficient or advantageous. However, the term "novel approach" should be used cautiously, as all birds were previously exposed to Figaro demonstrating this technique. The ability of Goffin's cockatoos to retain and recall observed demonstrations over extended periods remains uncertain but cannot be ruled out. Studies on long-term memory in animals (Borrego & Dowling, 2016; Chow et al., 2017; Shaw & Harvey, 2020; Tello-Ramos et al., 2019) suggest such retention is possible. However, prior experiments with Goffin's cockatoos indicate that they do not appear to rely on social cues when exploring novel objects (Auersperg et al., 2014; Szabo et al., 2017).

Figaro's technique demonstrates higher efficiency by reducing the number of motions required, thereby saving time. However, it demands greater precision and stick control, which represents a trade-off between efficiency and effort. Kiwi and Pipin's ability to flexibly switch to this technique while maintaining and improving speed suggests that boldness might influence flexibility (Frost et al., 2006). Figaro, Kiwi, and Pipin are higher-ranking, older, stronger (Adelmant et al., 2024a), and bolder males (Rössler, 2024)—traits frequently associated in the literature with increased exploratory behavior and risk-taking propensity (Carere et al., 2005; Frost et al., 2007; Hopper et al., 2014; Overington et al., 2011; Spoolder et al., 1996). These personality traits or cognitive styles may, in part, explain why precisely these individuals demonstrated an improvement in effectiveness, in contrast to the other subjects. Although sample size limits statistical power for identifying correlations between specific traits (e.g., age, sex, rank) and observed techniques, their behavior reflects a unique trade-off: optimizing speed while expending additional effort to meet the demands of precision required by Figaro's method. This highlights the role of cognitive flexibility in overcoming physical and behavioural constraints, allowing individuals to adopt strategies that balance efficiency and effort, and contradicts Sih et al. (2012) findings that fast behavioural types, characterised by bold, aggressive, active and exploratory tendencies, prioritize speed over accuracy.

The objective of the baseline test was to qualitatively determine which technique each bird used to solve the box, thereby establishing a baseline against which adaptations in the later, more complex box condition could be evaluated. Each bird demonstrated and quickly settled upon a unique and conservative technique within the Base Technique test; however, these techniques could roughly be grouped into four main categories based on common elements of tool interaction: *Figaro's Techniqe, Needling, Foot insertion* and *Entrance Securing.* The distribution of birds across these technique groups was relatively balanced, with 3 – 4 birds per group, except for *Figaro's Technique* that was used by only one bird, Figaro. Analysis of technique efficiency, measured by successful trial completion time, showed no significant differences between the four techniques, indicating an overall comparable success rate across techniques.

This aligns with findings by Cole et al. (2011) who reported that problem-solving abilities in wild great tits were independent of factors such as sex, age, body condition, and initial hesitation, instead pointing to inherent variability among individuals. This intrinsic variability may also characterize the individualized approaches observed among our captive-raised Goffin's cockatoos as both sexes and various weight classes were equally represented across the different baseline technique groups (with the exception of Figaro).

In a previous Innovation Arena experiment, Goffin's cockatoos demonstrated three distinct approaches to solving a single task, including both captive-raised and wild-caught individuals (Rössler et al., 2020). These birds utilized and combined multiple techniques, indicating that Goffin's do not rigidly adhere to previously learned motor routines when faced with the same task. Furthermore, the authors showed that captive-raised and wild-caught Goffin's did not differ in their capacity to innovate, differing instead in their levels of motivation. Similarly, in our experiment, individual variation in motivation was observed, such as initial hesitation to interact with the task box. However, this hesitation did not account for the individual differences in the techniques the birds ultimately established, highlighting that factors beyond motivation likely contribute to their diverse problem-solving strategies.

These observations lead us to propose that individual techniques might, in part, stem from personal preferences, individual strength, and notably also experience. When handling the tool, the birds could choose between using their beak, tongue, feet, or various combinations of these, potentially developing a preference based on individual control, strength, or proficiency with specific body parts. One hypothesis is that the birds may experiment with various techniques within their behavioral range until one succeeds; this initial success could then be reinforced, leading the bird to adopt it as their preferred approach (Rössler & Auersperg, 2022), accompanied by their ability to memorise complex motor sequences immediately (Auersperg et al., 2013). This is shown in the technique consistency across many experiments with Figaro (Auersperg et al., 2012, 2014; Osuna-Mascaró et al., 2022) as well as the consistency of birds using a single technique in each condition (with the exception of Kiwi and Pipin) across our experiments.

Individual differences were also shown in their side preferences. Individual side preference, defined as whether birds initially picked up the right or left side of the stick with their beaks, showed significant effects for 9 out of 11 birds in the baseline test and 8 out of 10 birds in the unbalanced test. Despite the small sample size, right- and left-side preferences were evenly distributed across individuals. This distribution suggests functional, individual-level asymmetry (Frasnelli & Vallortigara, 2018).

The footedness of the Goffins in our study was previously examined and showed strong preference for left footedness at both the species and individual levels (Colbourne et al., 2024). However, this footedness does not appear to correlate with the side preference observed. This discrepancy suggests the involvement of complex and probably independent lateralization processes between the eyes, feet and beak, depending on the action being performed (Rogers, 2007, 2008; Weir et al., 2004). Moreover, our findings contrast with those of Adelmant et al. (2024), who observed that Figaro exhibited a pronounced side bias, being seven times more likely to choose the left object over the right. Interestingly, Figaro was the only bird in our experiments to show no side preference at all.

These contrasting observations on lateralized behaviors suggest the need for further exploration. They hint at the possibility that individual side preferences may not be static but rather subject to variability, reflecting a degree of behavioral flexibility in interactions with novel objects and tasks. Combined with the previously mentioned variability in individual insertion techniques, these findings underscore the individual flexibility of Goffin's cockatoos in problem-solving contexts.

While the findings regarding individual techniques and technique changes were highly individualized, our results on weight discrimination in the unbalanced tool revealed a significant group-level effect. The Goffin’s cockatoos were more likely to complete the trial while the light side of the stick was inserted in the vertical condition, thereby controlling the heavier end with their beaks. This confirmed our prediction that grasping the heavier end can reduce the energetic cost associated with tool manipulation by minimizing the muscular effort required to counterbalance the tool's weight distribution (Eastough & Edwards, 2007; Halim et al., 2019). This strategy also enhances control and precision during manipulation, as holding the heavier end provides a more stable grip, reducing the likelihood of unintended tool movement (Hiramatsu et al., 2015; Paulun et al., 2016).

These findings align with those of the previous weight studies on Goffin's, demonstrating that birds can discriminate between visually identical objects based on weight and assess weight cues to make transport decisions (Adelmant et al., 2024a; P. J. Lambert et al., 2021). However, whereas Adelmant et al. (2024) found no significant preference for transporting balanced over unbalanced objects, our results suggest that when using an unbalanced stick tool, the birds paid specific attention to weight distribution-related cues.

We propose that this discrepancy stems from differences in the functional role of objects utilized in the respective study. In the referenced study, the unequal weight distribution of the objects did not directly influence the attainment of a food reward, as the objects were not actively employed in the reward acquisition process. We suggest that during transport decisions, weight distribution may hold less significance compared to scenarios where an object is used to perform direct manipulative actions. Sensimotor memory has previously been found to be task-dependent in humans and has been shown to be quite robust over time and recallable after interferences (Fu & Santello, 2015). In addition, the authors of the previous study (Adelmant et al., 2024) suggest that the dumbbell-shaped design of the object may have reduced the overall effect observed. This design probably allowed the birds to reduce the perceived weight difference between the two sides by gripping the centre of the object more firmly, a possibility facilitated by the inherent structural properties of the shape. In contrast, our object design featured a significantly more unequal weight distribution and a uniform surface that did not provide any specific areas that were easier to grip than others. Its design, along with its clear cause-and-effect functionality, suggests that Goffin's cockatoos do attend to cues of unequal weight distribution in this specific case, in contrast to the findings of Adelmant et al. (2024).

Overall, 8 out of 10 birds demonstrated either a technique change or weight discrimination, with three (Muppet, Dolittle, Pipin) showing both. The other two birds were Figaro and Mayday. Mayday's limited data points precluded conclusive significance testing; however, it is plausible that additional trials could have revealed some degree of change. Of her 23 successful trials in the vertical condition, 16 involved light-side (LS) completion. Figaro, on the other hand, presents a unique case (again). We do not believe he lacks the cognitive ability to assess weight cues, as demonstrated previously (Adelmant et al., 2024; P. J. Lambert et al., 2021). However, it is likely that the stick was not heavy enough to require such an assessment, and his technique appeared to be the most efficient regardless. We argue that if we had initially calculated each subject's maximum carryable weight, as done by Adelmant et al. (2024), we could have created objects specifically adapted to each bird. This would likely have yielded more inclusive results and minimized a few more degrees of freedom for each individual bird. However, this specific design allowed us to observe which birds adapted their technique through self-assessment and efficiency optimization (e.g. Kiwi & Pipin), rather than being compelled to adopt a different approach due to physical constraints.

Nevertheless, these results suggest that when adjusting to novel challenges, Goffin's consider multiple variables, including both the method of tool interaction (technique) and specific tool properties such as weight distribution. This highlights a complex, flexible approach to tool related problem-solving, suggesting interplay between multiple factors rather than a rigid, isolated response. Each bird demonstrated unique strategies rather than a uniform, species-wide approach, showcasing individual variation in problem-solving preferences and adaptability (Cole et al., 2011; Cole & Quinn, 2012). This sensitivity likely holds ecological significance, as optimizing tool use for weight and handling could enhance foraging efficiency and overall fitness.

We hypothesize that the observed differences, particularly in technique, are context-dependent. If the new box had been designed to completely prevent the use of baseline techniques, it is likely that more birds would have adapted their techniques, demonstrating their capacity for innovation under greater constraints. Such high degrees of constraints are evident in tasks like opening a Waiwai fruit, which requires the use of various tools and an assessment of sequential spatial relations, a behavior exhibited by two out of 18 captured wild Goffin's (O'Hara et al., 2021). While Goffin's appear to have a species-wide capacity for innovation (Mioduszewska et al., 2022) individual factors such as personality (e.g., experience, boldness, persistence, motivation) may influence which individuals ultimately innovate. To explore further what it would take to trigger, if possible, more birds to spontaneously innovate, future research could investigate whether sequentially minimizing the degrees of freedom in a stick-tool box experiment would have an increasing effect, as already seen in this experiment.

7. Conclusion

The findings of this study highlight the behavioural flexibility and adaptability of Goffin's cockatoos in response to novel challenges. The birds demonstrated a remarkable ability to integrate multiple variables, such as tool interaction techniques and weight distribution cues, into their problem-solving strategies. While the results support the hypothesis that Goffin's can assess and respond to unbalanced weight distributions in functional tools, they also reveal significant individual variation in technique adaptations and decision-making processes.

We observed changes in technique and adaptations to disproportionate weight cues in most subjects, with some birds demonstrating spontaneous strategy shifts even when not strictly necessary. This finding suggests a high degree of cognitive flexibility and exploratory behaviour, particularly among individuals of bolder, more experienced and more motivated personality traits.

The differences in findings compared to previous studies may be attributed to the functional role and design of the tools used. The stick-tool design used in this study, with its pronounced weight disparity and uniform gripping surfaces, is likely to have amplified the importance of weight cues. These design elements may have facilitated the birds' ability to optimize tool handling and control, thereby enhancing efficiency in solving the task.

We hypothesize that if task constraints were further increased—such as by completely eliminating baseline techniques—more birds might adapt their strategies, showcasing their innovative potential. This hypothesis is supported by observations of Goffins solving complex, naturalistic tasks such as opening a Waiwai fruit, which involves sequential tool use and spatial reasoning. To test this further, future studies could systematically minimize the degrees of freedom in tool-related tasks to determine whether all birds eventually adapt their techniques under such conditions.

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10. Appendix

10.1 Further information about the tested/not tested subjects

All subjects participating in the experiments were weighed both before and after testing, with the mean value used for analysis. Birds that did not participate were partly weighed after the testing period concluded. The table below provides information on all individuals housed at the Goffin Lab.

Name	Sex	Age	Flighted	Used/Not Used	Weight (in grams)	Explanation of no participation/Testing procedure
Dolittle	M	13	Yes	Yes	274	
Doree	F	3	Yes	No		Doree is one of the youngest birds and has had no previous experience of either with previous weight studies or with a stick-tool-box apparatus and was not willing to approach the apparatus.
Figaro	M	17	Yes	Yes	322.5	
Fini	F	17	Yes	Yes	258.5	
Heidi	F	14	No	Yes	261	Due to a lack of interest in the initial three sessions of the unbalanced test, testing with Heidi was paused. Upon completing tests with other subjects, the subject was re-evaluated from Session 4 onwards and demonstrated exceptional performance. To shorten the testing period, we decided to conduct tests twice daily with her, once in the morning and once in the afternoon, with a minimum interval of five hours between sessions.
Irene	F	7	Yes	No		Being one of the most neophobic birds of the group, she was scared of the apparatus.
Jane	F	7	Yes	No	276	Like in Irene, very neophobic and did not show interest in the apparatus.
Kiwi	M	14	Yes	Yes	326	
Mayday	F	13	Yes	Yes	233.67	

Moneypenny	F	14	Yes	Yes	261.25	
Muppet	M	14	Yes	Yes	284.5	
Muki	M	13	Yes	No		Muki is known for trusting only a few humans. He was hesitant to come into the testing room and further explore the box.
Olympia	F	14	No	Only in Base Technique	226	After successfully completing the Base Technique, she showed no interest in continuing with the Unbalanced test, usually only throwing the stick deliberately. She is also the only bird that does not respond to the GO! command, so her trials began with the stick being placed in front of her.
Pipin	M	16	No	Yes	311	
Renki	M	4	Yes	No	319	One of our 3 youngest birds, lacks preexperience. Although motivated, he could not figure out sticking the stick tool into the box after a whole session.
Rosie	F	3	Yes	No		One of our 3 youngest birds, lacks preexperience. Additionally scared of the apparatus.
Titus	M	7	Yes	No	310	Was completely uninterested in the apparatus.
Zozo	M	14	Yes	Yes	302.5	

10.2 Model descriptions

Model 1)

Model Overview

To investigate differences in trial times among bird groups, we analyzed the log-transformed trial times using a linear mixed-effects model. The model included **Technique group**, **Session**, and a random intercept for **Subject** including a random slope for **Session**.

$$log.TrialTime \sim Group + Session + (1 + Session \mid Subject)$$

Model stability

the stability of the linear mixed-effects model was evaluated using a method from Nieuwenhuis et al., (2012) which assesses model robustness by systematically excluding levels of the random effects with the glmm.model.stab function. The results suggest that while some variations exist, the estimates for both fixed and random effects are reasonably stable.

Overall Model Results

The model summary indicated significant fixed effects of **Session** on trial times ($F(1, 9.55) = 89.72$, $p < 0.001$), while the effect of **Technique group** was not statistically significant ($F(3, 6.95) = 2.64$, $p = 0.131$).

Between-Group Comparisons

Post-hoc pairwise comparisons using the **emmeans** package yielded the following estimated marginal means (EMM) for each Technique group: See Model output Appendix 10.3.

These results indicate that while there were variations in estimated trial times among different technique groups, none of the differences reached statistical significance.

Model Diagnostics

Model diagnostics assessed the stability and assumptions of the mixed-effects model. The variance inflation factors (VIF) indicated no multicollinearity issues, with a maximum VIF of 1.0001. Additionally, the model showed stable parameter estimates, with minimal ranges between the original and minimum/maximum estimates for fixed effects, suggesting reliability in our findings.

```
                    GVIF Df GVIF^(1/(2*Df))
Technique.group 1.000617  3        1.000103
Session         1.000617  1        1.000308
```

Model 2)

Model Overview

To analyze the factors influencing the likelihood of successful insertions using the light-side (LS) technique, a generalized linear mixed-effects model (GLMM) was specified. The model w as designed to account for both fixed and random effects within the dataset. The model is rep resented as follows:

CompletionWeightNum ~ ConditionSlit +
z.session + ToolPosition + z.weight + Sex + Group + Technique +
(1+z.session+ToolPosition.RW+ConditionSlit.V| Subject) +
(1+ToolPosition.RW || Subject.date)

To model completionweight we included conditionslit as test predictor, while includi ng session, etc.. as control predictors. To account for pseudoreplication and repeated measurements of the same individuals (also within one day) we included subject and subject.date as random intercept effects.

Model Fitting:

To address convergence issues, we fitted the model using the bobyqa optimizer with increase d iteration limits. The final model included random intercepts and slopes for Session, ToolPo sition, and Condition Slit nested within Subject and Subject.Date.

Model Stability

The initial model reported a VIF of 5.28, indicating potential collinearity issues, especially bet ween the predictors Sex and Weight. The model was subsequently refitted without Sex, whic h resulted in a lower maximum VIF of 2.03, suggesting improved collinearity. Model is repre sented as follows:

CompletionWeightNum ~ ConditionSlit +
z.session + ToolPosition + z.weight + Group + Technique +
(1+z.session+ToolPosition.RW+ConditionSlit.V| Subject) +
(1+ToolPosition.RW || Subject.date)

Using the glmm.model.stab function, stability was assessed by removing random effect level s iteratively, confirming model robustness despite variability across some predictors. To furt her investigate model stability, an additional analysis excluded one outlier subject ("MAY"). Both models showed similar effects (original Condition effect: 1.83, excluding Mayday; 1.79) , suggesting that the inclusion of the outlier did not substantially affect the model's overall int erpretation.

10.3 Model Outputs

Model 1)

Results of the full model							
Term	Estimate	SE	lower cl	upper cl	F	df	P-value
Intercept	2.4545	0.3809	1.646	3.2556			
TechniqueFoot (1)	0.6925	0.4156	-0.2179	1.6361			
TechniqueNeedling (1)	0.426	0.4291	-0.4646	1.3431			
TechniqueSecuring (1)	1.0642	0.4291	0.1312	2.0266	2.640903	1, 9.55	0.1314315
Session	-0.2574	0.0272	-0.3115	-0.2046	89.715774	3, 6.95	0.0000037
(1) Technique was dummy coded with 'Figaro' being the reference category.							

Model Estimates					
	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	2.4545	0.3809	7.5512	6.4448	0.0003
Technique.groupFoot	0.6925	0.4156	6.9549	1.6664	0.1399
Technique.groupNeedling	0.426	0.4291	6.9454	0.9929	0.3541
Technique.groupSecuring	1.0642	0.4291	6.9477	2.4799	0.0425
Session	-0.2574	0.0272	9.5455	-9.4718	0

Confidence intervals			
	orig	X2.5.	X97.5.
(Intercept)	2.4545	1.646	3.2556
Technique.groupFoot	0.6925	-0.2179	1.6361
Technique.groupNeedling	0.426	-0.4646	1.3431
Technique.groupSecuring	1.0642	0.1312	2.0266
Session	-0.2574	-0.3115	-0.2046

p-values for individual fixed effects:

Technique.group	2.510495	0.8368316	3	6.953138	2.640903	0.1314315
Session	28.428537	28.4285369	1	9.545481	89.715774	0.0000037

Model 2)

Results of the full model							
Term	Estimate	SE	lower cl	upper cl	χ^2	df	P-value
Intercept	-0.5119	0.6227	-1.8115	0.6665			
ConditionSlitV (1)	1.8337	0.5995	0.7525	3.0598	8.072	1	0.0045
z.session (2)	-0.1238	0.1374	-0.4195	0.1285	0.7852	1	0.3756
ToolPositionRW (1)	-0.0394	1.48	-2.8184	2.7908	0.0007	1	0.9787
z.weight (2)	-0.222	0.1414	-0.5586	0.0877	2.6668	1	0.1025
GroupVH (1)	-0.5285	0.2262	-1.1045	0.0465	4.7874	1	0.0287
TechniqueFoot (1)	1.0026	0.2506	0.4251	1.7396			
TechniqueNeedling (1)	1.2103	0.2977	0.5192	1.991	15.4725	2	0.0004
(1) ConditionSlit; ToolPosition; Group; and Technique were dummy coded with ‘H’; ‘LW’; ‘HV’; and ‘Figaro’ being the reference categories respectively.							
(2) Session and weight were z-transformed to a mean of 0 and SD of 1. Original mean +- SD of 6.05+-2.75 and 287.6+-28.8 respectively							

Model estimates					
	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	-0.5119	0.6227	-0.8221	0.411	
ConditionSlitV	1.8337	0.5995	3.0586	0.0022	
z.session	-0.1238	0.1374	-0.9011	0.3675	
ToolPositionRW	-0.0394	1.48	-0.0266	0.9788	
z.weight	-0.222	0.1414	-1.5701	0.1164	
GroupVH	-0.5285	0.2262	-2.3367	0.0195	
TechniqueFoot	1.0026	0.2506	4.0005	0.0001	
TechniqueNeedling	1.2103	0.2977	4.065	0	

Confidence intervals			
	orig	X2.5.	X97.5.
(Intercept)	-0.5119	-1.8115	0.6665
ConditionSlitV	1.8337	0.7525	3.0598
z.session	-0.1238	-0.4195	0.1285
ToolPositionRW	-0.0394	-2.8184	2.7908
z.weight	-0.222	-0.5586	0.0877
GroupVH	-0.5285	-1.1045	0.0465
TechniqueFoot	1.0026	0.4251	1.7396
TechniqueNeedling	1.2103	0.5192	1.991

p-values for individual fixed effects

none	-750.5273	1543.055	NA	NA	NA

ConditionSlit	-754.5633	1549.127	8.072	1	0.0045
z.session	-750.9199	1541.84	0.7852	1	0.3756
ToolPosition	-750.5277	1541.055	0.0007	1	0.9787
z.weight	-751.8608	1543.722	2.6668	1	0.1025
Group	-752.921	1545.842	4.7874	1	0.0287
Technique	-758.2636	1554.527	15.4725	2	0.0004

10.4 Mean trial times

Subject	Base Technique Test (in seconds)	Unbalanced Test (in seconds)	% increase
FIN	8.24	18.3	122.35
ZOZ	8.32	17.8	113.46
FIG	8.53	9.98	17.02
PIP	8.79	35.0	298.86
KIW	12.4	15.2	22.58
MAY	14.4	47.5	229.86
MON	18.7	35.5	89.79
HEI	21.0	20.2	-3.81
OLY	30.3	NA	NA
DOL	30.3	47.9	58.29
MUP	32.5	53.3	64.92

10.5 Side preferences

Base Technique:

```
Subject L_count R_count total_choices  p_value preference
   <fct>        <int>     <int>            <int>     <dbl> <chr>
 1 DOL              0        50               50 1.78e-15 Significant
 2 FIG             24        25               49 1    e+ 0 Not Significant
 3 FIN              3        47               50 3.71e-11 Significant
 4 HEI             28        22               50 4.80e- 1 Not Significant
 5 KIW              0        50               50 1.78e-15 Significant
 6 MAY             46         0               50 4.46e-10 Significant
 7 MON             42         8               50 1.16e- 6 Significant
 8 MUP             50         0               50 1.78e-15 Significant
 9 OLY             33        14               47 7.94e- 3 Significant
10 PIP             50         0               50 1.78e-15 Significant
11 ZOZ             49         1               50 9.06e-14 Significant
```

Unbalaced test:

```
   Subject L_count R_count total_choices  p_value preference
   <fct>        <int>     <int>            <int>     <dbl> <chr>
 1 DOL              0       169              169 2.67e-51 Significant
 2 FIG             95       101              196 7.21e- 1 Not Significant
 3 FIN              0       200              200 1.24e-60 Significant
 4 HEI              4       169              173 6.16e-45 Significant
 5 KIW              6       194              200 1.06e-49 Significant
 6 MAY            115         0              115 4.81e-35 Significant
 7 MON             48        67              115 9.28e- 2 Not Significant
 8 MUP            163         8              171 1.08e-38 Significant
 9 PIP            170         0              170 1.34e-51 Significant
10 ZOZ            185         6              191 4.10e-47 Significant
```

10.6 Technique descriptions Unbalanced Test

Figaro:

Throughout all 10 sessions, beginning with the horizontal slit, Figaro consistently maintained his previously established technique from the baseline test. Specifically, he grasped the stick by its very end and inserted it distal end first into the box (see *Figaro's Technique*). During Session 1, Trial 1, Figaro spent approximately 150 seconds familiarizing himself with the new box. While holding the stick at its end, he repeatedly attempted to locate an entry point, circling the box and testing various sides before finally inserting the stick into the front slit. Once successful, he quickly pushed the nut and completed the trial in under 5 minutes. He showed no hesitation or difficulties handling the new unbalanced stick. In all subsequent horizontal trials, Figaro consistently and successfully employed this technique.

In the first trial of the vertical condition, Figaro immediately utilized his established technique, inserting the stick successfully within 5 seconds and completing the trial in approximately 31 seconds, indicating he had no difficulty adapting to the new condition. He proceeded to complete all trials in the vertical condition successfully, with the exception of four trials (Session 4, Trials 7–10), where he appeared distracted by a sound and showed no interest in continuing.

Fini:

When first introduced to the new box, she completed the trial without hesitation, employing her established technique in approximately 9 seconds. She successfully completed 98 out of 100 trials in the horizontal condition. Upon encountering the vertical condition for the first time, Fini immediately demonstrated familiarity by inserting the stick with her usual technique. On at least two occasions of the first trial, the stick slid down the ramp and ended up outside the box, prompting her to adapt by inserting the other end of the stick instead, displaying flexible switching behavior. She completed the first vertical trial in approximately 53 seconds and subsequently succeeded in all 100 trials in this condition.

Mayday:

In the first session of the horizontal condition, she did not interact with the box at all. In the second session, she completed only the first trial using her established needling technique. During the second trial, she inserted the stick as before but struggled to control it within the box, repeatedly removing and reinserting the stick and displaying switching behavior. She was unable to complete the trial within 5 minutes. From sessions 3 to 10, she successfully completed all remaining trials, resulting in a total of 81 out of 100 successful trials in the horizontal condition. Aside from her initial hesitation, she did not deviate from her previously established baseline technique.

In the vertical condition, however, she encountered considerable difficulty. Her needling technique proved less effective, as the vertical slit caused the stick to fall out frequently, seemingly reducing her control without the leverage provided by the previous horizontal slit. After numerous unsuccessful attempts to push the nut, she seemingly lost motivation and withdrew after the first two sessions. From sessions 3 to 8, she completed only 3 out of 60 trials, without any consecutive successful trials within a session. Although she showed repeated switching behavior, she neither altered her primary technique nor experimented with different approaches.

In sessions 9 and 10, however, she completed all trials successfully, bringing her total to 23 s uccessful trials out of 100 in the vertical condition. Despite her limited flexibility in adopting new techniques, her improved control over the stick suggests an element of learning through practice

<u>Zozo:</u>
When first introduced to the horizontal condition, Zozo displayed no hesitation in applying his baseline foot-insertion technique, which was immediately effective. In subsequent trials, he maintained this technique consistently, while also displaying switching behavior. Zozo successfully completed 98 out of 100 trials in the horizontal condition.

Similarly, upon encountering the vertical condition, he showed no hesitation in employing his foot-insertion technique and achieved success right away. Zozo appeared to have no difficulty adapting to a) the change in slit orientation or b) controlling the stick to reach the bait once inserted. He frequently demonstrated switching behavior in the vertical condition as well, successfully completing 90 out of 100 trials.

<u>Heidi:</u>
In the initial trial of Session 1, she approached the box, circling it and seemingly inspecting it with apparent curiosity before returning to her chair, showing limited interest in further interaction. During the second trial, she attempted to insert the stick using her established foot insertion technique. After several unsuccessful attempts, she discarded the stick, leading to an incomplete trial. In Session 2, Trial 1, she managed to insert the stick with her foot technique, but struggled to maneuver it effectively within the box to push the bait, likely leading to frustration and eventual disengagement. This pattern of brief engagement followed by disengagement persisted until Session 4.

A breakthrough occurred in Session 5, Trial 1, when she successfully completed a trial after repeated stick insertions and switchings of the stick. In this instance, she successfully pushed the bait within five minutes. From this point forward, her performance improved substantially, with all subsequent trials completed successfully. In total, she completed 60 out of 100 trials in the vertical condition.

In the horizontal condition, she exhibited no hesitation in picking up the stick and attempting insertion using her foot technique. After two initial drops, she successfully inserted the stick and pushed the bait within five minutes. Throughout all subsequent trials, she consistently employed the foot insertion technique, completing all 100 trials successfully using this method.

10.7 Reference videos

https://drive.google.com/drive/folders/19cLp7UzA3IbW9Q6M7edWnzEhifD0lQZc?usp=drive_link