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Handling techniques of a disbalanced stick tool in the Goffin's cockatoo (Cacatua goffiniana)

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Article

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Abstract

Parrots (Psittaciformes) exhibit unique morphological and behavioral traits that enable flexible, dexterous tool use, often comparable to that of 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 remains unexplored. This study examined how Goffin's cockatoos managed an unbalanced stick tool and the individual strategies they used to complete a stick-tool box task. We carried out a series of experiments using a setup with different levels of freedom, focusing on variations in insertion techniques and the birds' ability to distinguish unequal weight distributions. At the group level, the cockatoos tended to handle the stick with the center of mass positioned closer to their grip. The birds also demonstrated highly individualized adaptations in their techniques when solving unfamiliar problems. We suggest that individuals that did not modify their techniques in this setup may still be capable of doing so under greater task constraints. Overall, these findings provide the first evidence that Goffin's cockatoos can detect and adjust to uneven weight distribution in tools, underscoring their behavioral flexibility and sensitivity to physical tool properties.

Introduction

Sticks represent a versatile tool category across tool using animals, serving various functions from simple self-scratching[1], to extractive foraging by raking, probing or poking otherwise out-of-reach for food[2,3]. Extractive stick tool use has been extensively studied in our closest relatives, the chimpanzees, since Jane Goodall's groundbreaking Gombe observations in 1964[4]. However, the past three decades have sparked increasing interest in avian tool use as well[5]. Despite the deep evolutionary divergence between birds and primates, both in cognition and morphology, experiments have demonstrated comparable sophisticated tool use and manufacture modes in two corvid species and at least one parrot[6,7,8].

Notably, parrots have evolved novel cranio-morphological adaptations, specialized for nut-cracking and seed dehusking[9]. Their tongue-and-beak apparatus typically resembles a multifunctional tool, combining musculoskeletal adaptations[10,11] that enable high dexterity with densely innervated papillae that support precise haptic exploration of objects within the beak[12]. These novel adaptations can be repurposed for tool handling by flexibly rearranging habitual movements and pressure points[13,14]. In both the wild and laboratory settings, the Goffin's cockatoo has proven to be a proficient tool user[13,15,16]. Their extreme level of dexterity may be best exemplified by the tool assisted opening of Waiwai fruits[15]: In the wild, Goffin's cockatoos were observed to carpent and use up to three distinct stick tools in succession, each serving a specific function in the multi-step process of accessing the contents of a hard shelled fruit. First, the birds manufactured and forcefully pushed sturdy wedge-like tools into the dorsal side of the fruit to widen the exposed longitudinal fissure. Thereafter, sharp, short, knife-like tools were moved vertically in multiple piercing movements along the fissure to pierce through the fruits endocarp,

severing filaments and thereby allowing access to the embryonic contents. Finally, medium length, wider, spoon-like tools were first inserted through a vertical push and then levered up horizontally to scoop out the fruit contents. Throughout the extraction process, the cockatoos dynamically adjusted both the alignment of the tool and the fruit, with the coordination of one foot, both mandibles and tongue.

In captivity, a Goffin's cockatoo named Figaro was the first reported to spontaneously innovate tool use[13]. Initially seen attempting to rake in a stone pebble that had fallen on a wooden beam beyond a mesh barrier of the aviary using a stick. A subsequent experiment showed that Figaro would constantly manufacture tools out of the aviary construction material once the pebble had been replaced with a cashew nut. Interestingly, in a later social transmission experiment where a simple wire box with a flat floor contained the reward, birds from this flock emulated the behavior rather than directly imitating it[17]. Three additional male birds that eventually achieved successful tool use each employed techniques completely different from their demonstrator (Figaro) and to some extend different to each other: To insert the stick into the mesh box, two birds consistently gripped the distal end of the stick between their upper and lower mandibles, similar to Figaro's technique. Another bird, however, placed the tool on the ground and advanced it through the mesh opening by repeatedly flicking it forward with its tongue. Figaro also inserted the tools at varying grid heights, continuously repositioning the distal end of the stick and adjusting its placement in response to the reward's movement. By contrast, the three observer birds kept the entire tool on the ground, inserted it parallel to the reward, and knocked the food outward with a quick lateral motion toward the side.Individual differences in problem-solving strategies were likewise apparent in a more advanced composite tool experiment[16]. While three birds consistently managed to obtain the reward, each displayed distinct approaches in grip type, insertion method, and spatial handling of the stick tool. This diversity in technique suggests innovative, non-stereotyped behavior and highlights the species' flexible cognitive mechanisms underlying novel tool use.

The pronounced individual differences in technique found in these studies imply that, while social observation can convey the basic idea behind a problem-solving task, the detailed execution of the solution must be independently innovated. Once a successful method is identified, it tends to become reinforced and consistently reused by the individual, reflecting a learning process rooted in active exploration and rapid reinforcement rather than social transmission[18]. Ecological explanations for individual differences in problem-solving within groups involve both biotic and abiotic factors[19]. Biotic factors comprise sex, age, genetic makeup, social group interactions, neophobic or neophilic tendencies[20], and competition for resources among conspecifics. Abiotic factors include the environmental context in which the animal is raised and obtains food[19].

Complex tool use is considered an advanced foraging adaptation in opportunistic extractive foragers, enabling greater efficiency in obtaining resources[21]. In comparison, assessing the weight of food or tools seems to be a more fundamental capability associated with optimal foraging theory, as even animals that do not engage in tool use can discriminate weight differences[22,23,24,25]. Understanding the perception and use of weight information in animals is key to uncovering the evolution of weight-related

cognitive abilities and the adaptive efficiency of behavior. Interestingly, primates have exhibited unexpected difficulties in acquiring weight discrimination skills[26,27,28]. Conversely, the limited comparable research on corvids and parrots has demonstrated that these birds can readily distinguish objects of differing weights[29,30,31]. In a study with Goffin's cockatoos, 7 of the 8 tested subjects successfully learned to discriminate between two visually identical objects that varied in weight, achieving criterion in an average of only 60 trials[32]. Their performance outperformed that of apes, requiring about 81% fewer trials to succeed.

In a follow-up experiment, Goffin's cockatoos demonstrated not only the ability to discriminate between two different weights but could also apply weight knowledge to a more functional context[33]. This was done in a series of binary choice experiments, in which Goffin's cockatoos were presented and had to transport, one of two visually identical kettle bells that differed either in total weight or in weight distribution. Even though both options were equally rewarding, the birds reliably favored carrying lighter objects over heavier ones in both walking and flying conditions. In contrast, when choosing between two dumbbells with the same overall weight but different weight distributions, balanced or unbalanced, the cockatoos showed no obvious preference. The researchers suggested that the weights on the dumbbells may have been spaced too closely for the imbalance to be perceived as problematic.

This study focused on investigating how captive Goffin's cockatoos integrated subject-specific stick-tool insertion techniques with weight discrimination abilities when handling an unbalanced stick tool.

In the first phase, we employed a stick-tool-box experiment using a balanced wooden stick, referred to as the Base Technique Test, to qualitatively examine individual differences in technique across 11 subjects. The apparatus consisted of a straightforward tool box in which subjects only needed to poke a reward located on a platform behind an insertion opening. We anticipated that the study would provide insight into individual strategies, recurring patterns, and their effects on successful task performance.

The second experiment, referred to as the Unbalanced Test, involved modifying the initial setup by introducing an unbalanced stick tool with one side markedly heavier than the other. In addition, the original insertion hole was replaced with two alternative entry types: a horizontal slit and a vertical slit (see Fig. 8). The horizontal slit reduced the subjects' freedom in technique choice because the lack of lateral support, previously provided by the hole opening, transferred control of sideways movement to the subjects. The vertical slit further increased task difficulty, as the stick no longer had a supporting surface at the opening, requiring subjects to fully manage the stick's weight during use. These simultaneous modifications were implemented to examine the subjects' reactions and behavioral adaptations.

We proposed that these experimental changes would prompt the birds to adapt their established techniques in a flexible manner to meet the demands of the altered box and increased complexity. In particular, we expected that birds would show greater modifications in insertion technique in the vertical slit condition, where they had to fully manage the tool's weight and movement, than in the horizontal slit

condition (1), which still offered horizontal support. Furthermore, 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 (2), which will also be reflected in their switching behaviour (3). This preference would likely arise because grasping and controlling the stick at its heavier end is easier due to its physical properties[34] and is therefore energetically less costly.

Results

Base Technique Test

With the conclusion of the Base Technique Test, 11 birds that participated were sorted into 4 groups that were defined by shared similarities in stick insertion technique, namely *Figaro's Technique, Needling, Foot Insertion* and *Entrance Securing*. It is noteworthy that all birds had their own unique techniques despite being grouped into one of four and had become consistent in 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 using the same technique. This suggests that subjects had developed and implemented their baseline techniques 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 techniques see Supplementary.

Figaro's Technique. The insertion strategy used by Figaro was notably different from that of the other individuals. Throughout the task, he relied entirely on coordinated movements of the beak and tongue and was the only subject to employ a "precision grip," in which the tool is stabilized between the tip of the upper mandible and the tip of the tongue (see Supplementary F1). Earlier studies indicate that this stick-insertion behavior is both highly practiced and well established[13,16,17]. In a typical sequence, Figaro first held the stick at one end between his upper and lower mandibles before positioning himself at an appropriate distance from the box. He then repositioned the stick so that it was secured either between the mandibles or between the tongue and upper mandible. From this configuration, he guided the far end of the stick into the opening, occasionally making brief, rapid adjustments to achieve proper alignment. In contrast to what previous observations would suggest[13,16,17], he more often gripped the stick between his mandibles than between the tongue and upper mandible (see Supplementary F1; F2) which is likely explained by the stick's size and mass.

Needling (Fig. 1). These individuals initially grasped one end of the stick between their mandibles and approached the box, bringing the proximal end toward the entrance while rotating their heads laterally. Mayday began by inserting a short segment of the proximal end, approximately 5 mm, into the opening while holding it in her mandibles. She then advanced the stick further by applying repeated forward movements with her tongue, while maintaining a relatively loose grip; the circular shape of the opening helped keep the stick in place.

In contrast, Fini and Kiwi, after positioning the proximal end near the entrance, immediately initiated a “needling” motion. Holding the stick loosely between their mandibles, they used their tongues to incrementally push it into the box until roughly half of its length had been inserted. Once the stick reached a stable halfway position within the box - such that it could no longer fall out - all subjects released their initial grip and repositioned to the distal end. From there, they grasped the distal portion relative to the box and completed the insertion with a single, final push. This insertion method had previously been reported for Fini[16], but in the present study it was systematically observed and recorded for Kiwi and Mayday for the first time.

Foot Insertion (Fig. 2). These individuals initially held one end of the stick between their mandibles and positioned the proximal end near the entrance opening. From this starting point, Heidi, Pipin, and Olympia used one foot to grip the stick around its middle section, whereas Zozo placed his foot closer to the proximal end. They then applied pressure with the foot to push the stick into the box, inserting at least one quarter of its length. The foot used differed across individuals, indicating possible lateralization in foot preference[35]. During the initial insertion, the subjects pushed the tip of the stick with the foot while simultaneously shifting their head position toward the distal end. Zozo and Heidi then secured the distal portion of the stick between their mandibles, released their foot grip, and completed the insertion in a single, continuous beak-driven motion. In contrast, Pipin and Olympia maintained a loose beak hold alongside the foot grip before releasing the foot. They subsequently advanced the stick using tongue-driven thrusts (i.e., needling), allowing it to slide further into the box. Once the stick was largely stabilized within the opening, they finalized the process with a beak push. Notably, Pipin and Olympia were the only individuals to integrate foot, tongue, and beak actions within a single insertion sequence. While this technique had previously been reported for Pipin in a composite tool task[15], the present study provides the first systematic documentation of its use by Olympia, Zozo, and Heidi.

Entrance Securing (Fig. 3). All three individuals began their insertion sequences by grasping one end of the stick with their mandibles and positioning it near the entrance of the box. They then stabilized the proximal end at the opening using their beak and/or tongue, such that it rested at the entrance while the distal end remained supported by the ground, creating an angle of roughly 45°. This configuration provided sufficient stability for the stick to remain in place, enabling the subjects to either release it temporarily or move away without disrupting its position.

Moneypenny held the stick at the entrance between her mandibles, stepped back, and subsequently grasped the distal end, completing the insertion with a single forward push. Muppet, in contrast, secured the stick using both beak and foot, then moved his beak along the length of the stick until reaching the distal end, where he finished the insertion in one continuous motion. Dolittle first fixed the proximal end using his beak and tongue, then advanced along the stick with his beak to a point approximately 1–2 cm from the distal tip. From there, he pushed the stick about two-thirds of the way into the box in a single movement, repositioned his grip to the very end, and completed the insertion with a final push. Although both Dolittle and Muppet were physically able to release the stick entirely, as observed in Moneypenny, they appeared to favor maintaining continuous contact while guiding the tool into position.

Overall we did not find evidence for an effect of technique on total trial time ($F_{(3, 6.956)} = 2.642$, $p = 0.13$). Estimated total trial time (while controlling for session number) was 10.63+-2.15 (mean+-SD); 8.15+-1.92; 15.44+-3.64; 5.32+-2.23 for Foot; Needling; Securing; and Figaro's Technique, respectively. Birds became faster over sessions ($\beta = 0.362$, $SE = 0.038$, $F_{(1, 9.547)} = 89.724$, $p < 0.001$). (see Fig. 4; Supplementary S1).

Unbalanced Test

Unbalanced weight discrimination

We found strong evidence that the probability to finish the task with the light-end of the stick inserted differed between conditions ($\chi^2_{(1)} = 8.072$, $p < 0.01$). To be precise, in the vertical condition birds were more likely to finish with the light-end of the stick (in 487 out of 745 trials (65.4%)), than in the horizontal condition (in 446 out of 874 trials (51.0%)) (see Fig. 5; Supplementary S2).

Switching of stick sides occurred in 230 out of 776 trials (29.6%), and we found moderate evidence for an effect of which side of the stick was picked up first ($\chi^2_{(1)} = 6.534$, $p = 0.011$). Birds were twice as likely to switch when the incorrect side was picked up first (in 156 out of 391 trials (39.9%)), than when the correct side was picked up first (in 74 out of 385 trials (19.2%)) for both conditions (see Fig. 6; Supplementary S3).

Technique changes

When confronted with the horizontal or vertical box openings, half of the subjects (5/10) modified their insertion techniques at least once. Remarkably, all three birds that had previously employed the *Entrance Securing* technique in the Base Technique Test switched to alternative approaches, likely because the removal of lateral and horizontal support prevented effective stabilization of the stick using their former method. Dolittle adopted a *Needling* strategy, while Muppet changed to the *Foot Insertion* method. Both subjects used their newly developed approaches consistently throughout all unbalanced-condition trials, irrespective of whether they were tested in the initial or later opening orientation (see Supplementary Table S1). In contrast, Moneypenny uniquely exhibited repeated technique shifts, consistently applying *Figaro's Technique* in the vertical condition and a *Foot Insertion*–like technique in the horizontal condition.

Surprisingly, two additional subjects changed technique despite also demonstrating successful consecutive trials with their previously established Base Techniques. Kiwi, from the first session onwards, spontaneously switched between using *Figaro's Technique* and his established *Needling* base technique in the vertical condition. Out of 100 trials, he completed 78 using *Figaro's Technique* and 22 using *Needling*. Trial time analyses revealed that his mean completion time was 25.22 seconds with *Needling*, compared to 16.1 seconds with *Figaro's Technique*. In the subsequent horizontal condition, Kiwi

again alternated between the two strategies. Out of 100 trials, he completed 55 with *Figaro's Technique* and 45 with *Needling*, with mean trial times of 10.03 seconds and 13.27 seconds, respectively.

Like Kiwi, Pipin spontaneously switched from his Base Technique, *Foot Insertion*, to *Figaro's Technique*. In his first Unbalanced Test condition (vertical orientation), he flexibly alternated between the two techniques. Across 100 trials, he completed 23 trials using *Figaro's Technique* and 43 trials using *Foot insertion*. In the subsequent balanced test condition (horizontal orientation), Pipin reverted to his Base Technique. Trial-time analyses showed that, in the vertical condition, mean trial duration was substantially shorter when Pipin used *Figaro's Technique* (9.34 s) compared with *Foot Insertion* (47.55 s).

Discussion

Our study found that 8 out of 10 birds adapted flexibly to the more complex stick-and-box task with limited support by either altering their insertion methods or testing and adjusting to the stick's weight distribution, with three birds employing both strategies. These findings indicate that Goffin's cockatoos are able to recognize disproportionate weight balance in tools and modify their behavior accordingly.

More specifically, our first prediction (1) was partly confirmed as 5 birds altered their insertion technique when confronted with the vertical condition, however, 4 out of these also changed technique in the horizontal 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, seemingly carried this technique over into the subsequent condition, Moneypenny responded to each novel challenge by developing a distinct new solution. This pattern is consistent with previous findings[36] showing that apes confronted with a puzzle box requiring progressively more complex solution strategies readily abandoned earlier methods once those approaches were no longer effective. These results align also with findings from studies on kea and New Caledonian crows[37], which demonstrated that individuals readily adopted alternative solutions in a multi-access box task when previously successful strategies were no longer viable. Such behavior indicates a high level of behavioral flexibility, including inhibitory control and the capacity to overcome functional fixedness[38]. However, this does not necessarily mean that Moneypenny is more innovative than the other individuals. Rather, her repeated adjustments may reflect that her prior strategies were unsuitable for the new conditions, whereas the techniques used by other birds remained effective and could be applied without modification.

Perhaps more noteworthy was the occurrence of technique changes even when they were not strictly required—that is, instances in which individuals adopted alternative methods despite their existing strategies remaining effective. Both Kiwi and Pipin alternated between their baseline techniques and *Figaro's technique*. However, analysis of trial durations showed that *Figaro's technique* resulted in faster performance, indicating that it was the more efficient option for both individuals. This finding is

particularly compelling because, despite prior exposure to Figaro's demonstrations in earlier experiments, neither bird imitated his technique at that time[17]. This indicates that the birds did not adapt to the stick's imbalance by switching sides (see Fig. 6), but rather by spontaneously adjusting their technique. *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 improving speed suggests that boldness might influence flexibility[39]. Figaro, Kiwi, and Pipin are all adult, higher-ranking, strong[33], and bold[40] males, traits frequently associated in the literature with increased exploratory behavior and risk-taking propensity[39,41,42,43,44]. Such personality characteristics or cognitive styles may help account for why only these individuals demonstrated increased efficiency compared to the remaining subjects.

The Goffin's cockatoos showed a significant preference for completing trials with the lighter end of the unbalanced stick inserted, exceeding chance levels and thereby supporting hypothesis (2). At the group level, this effect was particularly evident in the vertical condition, where insertions involving the lighter end occurred significantly more often than the expected 50% baseline (see Fig. 5). This pattern was further reinforced by switching behaviour (3): individuals were more likely to reverse their initial choice of stick end when they first selected the heavier side (see Fig. 6). Together, these results indicate that Goffin's cockatoos are capable not only of discriminating weight differences in otherwise identical objects and using this information to guide transport decisions[32,33], but also of evaluating and responding to uneven weight distribution within a tool. In contrast to Adelmant et al.[33], who reported no clear preference for transporting balanced over unbalanced objects, our findings suggest that when engaging with an unbalanced stick tool, the birds specifically attend to cues related to weight distribution. We propose that the observed discrepancy reflects differences in the functional role of the objects used in the respective studies. In the referenced case, unequal weight distribution did not affect reward acquisition, as the objects were not actively employed to obtain food. We therefore suggest that weight distribution may be less influential during transport decisions than in contexts where objects are directly used to manipulate or access rewards. Furthermore, the authors of the study argue that the dumbbell-shaped design may have reduced the strength of the observed effect. This shape likely enabled the birds to compensate for weight differences by gripping the object at its centre, thereby minimizing the perception of imbalance due to its structural affordances. In comparison, our object design involved a markedly stronger weight asymmetry and a homogeneous surface without any distinct grip advantages. Combined with its clear causal-functional structure, this suggests that Goffin's cockatoos are sensitive to uneven weight distribution in our setup, in contrast to Adelmant et al.[33].

Each bird demonstrated and quickly settled upon a unique and conservative technique within the Base Technique test resulting in 9 distinct techniques overall. Based on shared characteristics of tool interaction, these techniques could be organized into four main categories. The allocation of birds across the groups was relatively balanced, with each containing about 3–4 individuals, apart from Figaro's Technique, which was unique to Figaro. Analysis of technique efficiency, assessed via

successful trial completion time, revealed no significant differences among the four techniques, suggesting broadly comparable performance across methods. This is consistent with previous work[45], which demonstrated that problem-solving performance in wild great tits was not explained by factors such as sex, age, body condition, or initial hesitation, but rather reflected substantial inter-individual variability.

Such intrinsic variability may also underlie the individually distinct approaches observed in captive-raised Goffin's cockatoos in the present study, particularly as both sexes and a range of body masses were evenly distributed across baseline technique groups (with the exception of Figaro). In a prior Innovation Arena experiment, Goffin's cockatoos likewise exhibited multiple distinct solution strategies for a single task, including both captive-raised and wild-caught individuals[46]. These birds not only employed different techniques but also combined them, indicating that they do not strictly adhere to previously learned motor patterns when encountering repeated problem contexts. The same study further reported no difference between captive-raised and wild-caught individuals in innovative capacity, but rather variation in motivation levels.

Similarly, we observed individual differences in motivation, such as varying degrees of initial engagement with the apparatus. However, this did not explain the diversity of techniques ultimately expressed, suggesting that additional factors contribute to the observed variation in problem-solving strategies. These may include individual preferences, differences in strength, and prior experience. While using the tool, the birds had the option of using the beak, tongue, feet, or combinations of these effectors, and may have shown preferences shaped by efficiency of control, physical capability, or coordination skill. One possible explanation is that individuals explore different actions within their behavioral repertoire until a successful solution emerges; this initial success may then be reinforced and consolidated into a preferred strategy[47], consistent with their ability to rapidly encode complex motor sequences[48]. This interpretation is supported by the high consistency of technique use across experiments in Figaro[13,16,17], as well as the general tendency for most individuals to maintain a single technique within each condition (with the exception of Kiwi and Pipin) across the present experiments.

The data indicate that Goffin's cockatoos do not rely on a single dimension when adapting to novel tasks, but instead incorporate both interaction technique and physical attributes such as weight distribution. This suggests a highly integrative form of problem-solving in which multiple variables are balanced to guide behavior. Rather than showing convergence on one strategy, each individual adopted its own solution pathway, emphasizing substantial inter-individual variability[45,49]. This sensitivity is likely of ecological relevance, as adjusting tool use according to weight and handling properties may improve foraging efficiency and thereby enhance overall fitness. We propose that the differences observed here, particularly in technique choice, are context-dependent. Had the apparatus been designed to fully preclude the use of baseline strategies, or had stick weights been individually calibrated to exceed each bird's handling capacity, it is plausible that a greater number of individuals would have modified their approaches, thereby revealing a broader capacity for innovation under increased constraints[15]. Although

Goffin's cockatoos appear to possess a species-wide propensity for innovation[50], individual differences, such as personality traits (e.g., experience, boldness, persistence, and motivation), may influence which birds ultimately generate novel solutions. Future work aimed at identifying the conditions that elicit spontaneous innovation could examine whether progressively reducing degrees of freedom in a stick-tool-box paradigm incrementally increases innovative responses, as tentatively suggested by the present findings.

Methods

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. 11 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 (with motivational issues), were tested. Testing took place between 12.10.2023 and 23.03.2024. All cockatoos in this study were captive-born and hand-raised. They are housed at the Goffin Lab Goldegg in St. Pölten, Austria, within a large, socially and environmentally enriched aviary system. The facility comprises an indoor enclosure of approximately 45 m² with a variable height between 3 and 6 m, and an outdoor aviary of around 200 m² with heights ranging from 3 to 4.5 m. The indoor section is climate-controlled, with a minimum winter temperature of 17°C, and follows a 12-hour light–dark cycle. Birds receive an ad libitum diet consisting of raw and cooked seeds, boiled vegetables, fresh and dried fruits, and water. Individuals are identifiable via colored leg rings. For voluntary experimental sessions, birds are called by name into an indoor testing room, where they are temporarily separated from the group under visual isolation to minimize the possibility of social learning.

Ethics

Prior to the commencement of testing, this study received approval from the Ethics and Animal Welfare Committee of the University of Veterinary Medicine Vienna (ETK-179/11/2022), in accordance with national legislation and guidelines for good scientific practice. All individuals were held under valid CITES permits and registered with the local animal welfare authority (Bezirkshauptmannschaft St. Pölten, Schmiedgasse 4–6, A-3100 St. Pölten, Austria). Housing conditions 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). As the procedures were non-invasive, appetitive in nature, and based exclusively on behavioral observations, the work did not fall under the definition of animal experimentation according to the Austrian Animal Experiments Act (§ 2, Federal Law Gazette No. 501/1989).

Experimental History

Over the years, numerous studies have been conducted with these Goffin's using the sticktool-box setup in various variations, resulting in prior experience with the mechanics of the basic stick-type apparatuses for most birds[13,17,51,52,53,54,55]. The apparatuses used in the present study were the same as those employed about one year earlier by Osuna-Mascaró et al.[16], aside from minor adjustments. Consequently, no prolonged habituation phase was necessary. A subset of birds had previously participated in Lambert et al.[32], where 10 of the 11 individuals experienced weight selection tasks. In addition, six birds had substantial prior exposure to objects of varying weights and transport modes in the study by Adelmant et al.[33]. Nevertheless, none of the birds had encountered either the disbalanced stick used in this experiment or the newly designed slit openings (see Fig. 7).

Apparatus and Objects

Base Technique Test Apparatus and Tool

The apparatus in this study was based on the "single-tool" box design described by Osuna-Mascaró et al.[16] (see Fig. 7) and was used in its original, unmodified form. The box consisted entirely of Plexiglas and measured 22.5 × 20 × 20 cm (height × width × depth). It was fully transparent and contained an internal sliding plate with a central pole platform designed to hold the reward (see Fig. 7). The front panel included two openings: a 2 cm circular aperture positioned at 11.2 cm height and aligned with the internal platform for retrieval, as well as a lower horizontal slit through which the reward could be collected after moving down the internal ramp (see Fig. 7). In the Base Technique test, the stick tool was wooden, 17.5 cm long, and sufficiently long to reach the reward inside the box. It had a diameter of 7 mm and a mass of 7 g. A thin black midpoint marking was added solely for video coding purposes to distinguish the two halves of the stick (see Fig. 7).

Unbalanced Test apparatus and tools

The box in this study shared the same dimensions as the Base Technique box (see Fig. 7). It was made of Plexiglas with a black lid and sliding plate, while the remaining structure was completely transparent. In place of the pole platform, a rectangular ramp measuring 3 × 1.5 cm and 5 mm thick was fixed to the back of the box, enabling the reward to "float" more freely inside the apparatus (see Fig. 7). The removable front wall allowed two interchangeable panels to be inserted through a sliding mechanism. One panel featured a horizontal slit measuring 15 cm by 1 cm, while the other contained a vertical slit of the same size. As in the previous box designs, both front walls also included a lower slit for reward retrieval. 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 final 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.[33] 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 Fig. 7).

Experimental Procedure

Base Technique Test

The subjects completed five sessions of the Base Technique condition, with each session consisting of 10 trials. No more than one session was conducted per subject per day. At the start of each trial, the bird was positioned on the backrest of a chair facing the apparatus, which was placed on a table approximately 50 cm away. The box was baited with a piece of cashew nut (approximately ¼ of a small cashew or ⅛ of a large one), and the stick was placed about 5 cm in front of the box. Trials began with the subject in a seated position and the verbal cue “Los geht’s” (“Go!”). To avoid unintentional cueing (i.e., Clever Hans effects[56]), the experimenter remained behind the bird and out of its visual field throughout the trial. A trial was scored as successful if the subject retrieved the reward within 5 minutes from the moment it first picked up the stick. Trials were terminated and classified as unsuccessful if this time limit was exceeded, if the subject did not interact with the apparatus, or if it deliberately removed the stick from the table. Subjects were considered to have deliberately removed the stick when they picked it up, moved it to the edge of the table, and actively threw or dropped it away. Unintentional drops during handling did not count as deliberate removal events.

Unbalanced Test

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). Each group completed 10 sessions, each consisting of up to 10 trials for the respective opening condition. Following this stage, the groups switched to the alternative opening condition and completed 10 sessions with up to 10 trials per session using the Unbalanced Test apparatus and stick. Subjects were tested at a rate of no more than one session per day, except for Heidi, who began receiving two sessions per day after Session 6 of the initial vertical-opening condition. The trial procedure followed the same protocol as the Base Technique Test. The sticks were positioned approximately 5 cm in front of the box, though their placement varied randomly across trials. Randomization determined whether the heavy-side-marked or light-side-marked stick was used, as well as whether the marking appeared on the left or right side. This was done to control for learning effects and possible side biases, either inherent to the birds or caused by the marking. Every trial began with the birds in a sitting posture and the experimenter giving the command “Los gehts” (“Go!”). During the experiment, the experimenter was positioned behind the bird. A trial was scored as successful if the subject retrieved the reward within 5 minutes from the moment it first picked up the stick. Trials were terminated and classified as unsuccessful if this time limit was exceeded, if the subject did not interact with the apparatus, or if it deliberately removed the stick from the table. Subjects were considered to have deliberately removed the stick when they picked it up, moved it to the edge of the table, and actively threw or dropped it away. Unintentional drops during handling did not count as deliberate removal events.

Video Recording

All trials in both experiments were recorded using two IR FHD 1080p high-definition camcorders (model 3051LRM). The cameras were placed on opposite sides of the table, each providing a lateral view of the apparatus and the tool. Recording from two angles ensured complete coverage of stick manipulation, which was particularly important in situations where one perspective was partially obstructed, for example, when the bird’s head or beak blocked the view.

Statistical Analyses

To answer our research questions we ran three generalized linear mixed models[57]. With a first model we addressed how the technique used affected the total time needed to solve the apparatus in the Base Technique test. A second model was used to test if the probability of completing the trials with the light end differs between the horizontal and vertical entry for the Unbalanced Test. Finally, a third model was used to test if the correct side for pick up affects the likelihood to switch the tool.

The first model was a linear mixed model (LMM), fitted with restricted maximum likelihood using the lmer function of the package lmerTest (version 3.1-3)[58]. Inspection of the distribution of total trial time showed that this was strongly right-skewed, we therefore log-transformed (base e) total trial time to ensure an approximate symmetrical distribution of the response before including this in the model.

Because of our interest in technique, we fitted technique (with levels Foot; Needling; Securing; and Figaro) as the only fixed effect test predictor while session number (1–5) was included as a fixed effect control predictor. To account for repeated measurements, we included the individuals' identity as random intercept effect. The sample analyzed includes 535 observations.

The second model was generalized linear mixed model (GLMM) of the logistic kind fitted using the lmer function of the lme4 package (version 1.1–27.1)[59] with the family argument set to binomial. As a response we included whether individuals completed the test with the light end of the stick, and condition (horizontal or vertical) as single fixed effect test predictor. To control for their potential effects we included session number; weighted tool position (left or right); individuals' weight (233g-326g); group (HV or VH); and Technique (Foot; Needling; or Figaro) as control predictors. Sex (female or male) was initially included but was removed from the model due to increased collinearity with individuals' weight. As random intercept effects we included individuals' identity to account for repeated measurements, and to account for any day specific variation in motivation we included date nested in individuals' identity. Sample size for this model is 1619 observations.

Finally, we fitted another logistic linear mixed model that included whether an individual switched in a trial (no or yes) as a response. Correct pick-up side (no or yes) was included as single fixed effect test predictor. To control for potential confounding effect we included technique (Foot; Needling; or Figaro) and overall trial number (1-100) as control predictors. Similar to model two, individuals' identity and date nested in individuals' identity were included as random intercept effects. Sample size for model 3 is 776 observations.

All models were fitted in R (version 4.5.2)[60]. Before fitting each model, we z-transformed each covariate to ease model convergence and achieve easier interpretable coefficients[61]. In each model we included all theoretical identifiable random slopes and correlation parameters between random intercepts and slopes (maximal model)[62,63]. After model fitting, we visually confirmed that the best linear unbiased predictors (BLUPs) per level of the random effects were approximately normally distributed. We confirmed that the model assumption regarding normally distributed and homogeneous residuals were not violated for model 1 by inspection of a qq-plot and a residual versus fitted plot[64]. We verified the absence of collinearity by calculating the variance inflation factor for each of the final models that included only main effects using the function vif of the car package (version 3.0–12)[65]. Finally, for each model we assessed model stability by refitting the model while excluding each level of the random intercept in turn and comparing these estimates to those from the full model fitted to all observations[66]. This indicated that models 2 and 3 were of moderate stability in the control predictors (estimates showed increased variability when subjects were excluded), though estimates of test predictors were not affected, thus results should be interpreted with caution.

In model 1, the significance of the effect of technique was tested by means of the Satterthwaite approximation[67]. Significance of test predictors in both logistic models was tested by applying likelihood

ratio tests[68] using the drop1 function. We calculated confidence intervals by means of 1,000 parametric bootstraps using the bootMer function of the lme4 package. Post-hoc pairwise comparisons were applied using the emmeans package (version 1.7.2)[69]. Figures were created using the package ggplot2[70].

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

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Author contributions statement

Ö.N. and A.A. conceived and designed the experiments. Ö.N. conducted and video-coded all experiments. R.F. and Ö.N. analysed the data and generated plots and figures. A.A. acquired funding for the study. The first draft was written by Ö.N and edited by A.A. All authors reviewed the manuscript.

Additional information

Supplementary Information
Accompanies this paper.

Competing interests

The authors declare no competing interests.

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Figures

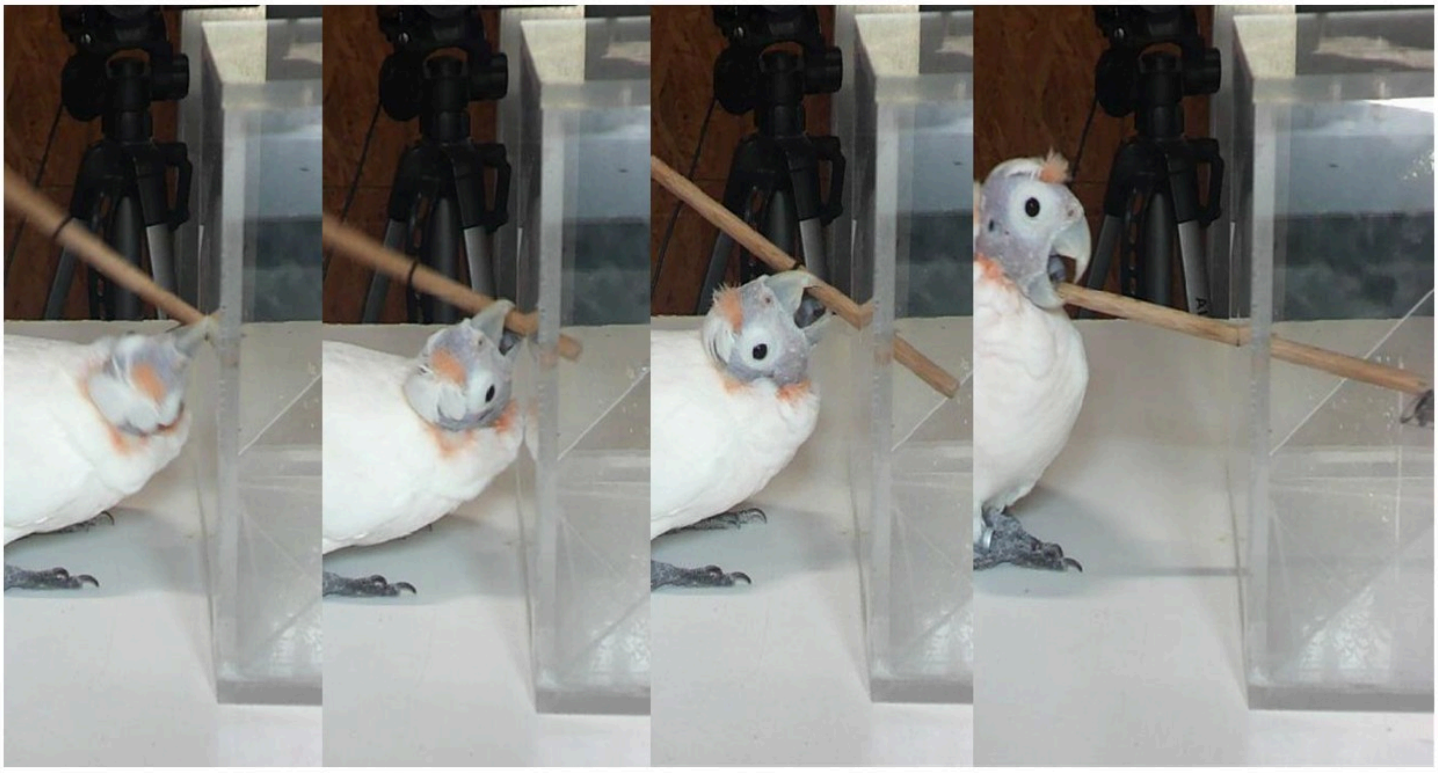


Figure 1

Step-by-step snapshots of Fini demonstrating the needling technique. After lifting one end of the stick with her beak, she guided the proximal end toward the opening. She then held the stick loosely between her mandibles and repeatedly pushed it deeper into the box using tongue thrusts. Once the stick was halfway inserted, Fini moved to the distal end and finalized the insertion with one push of her beak.

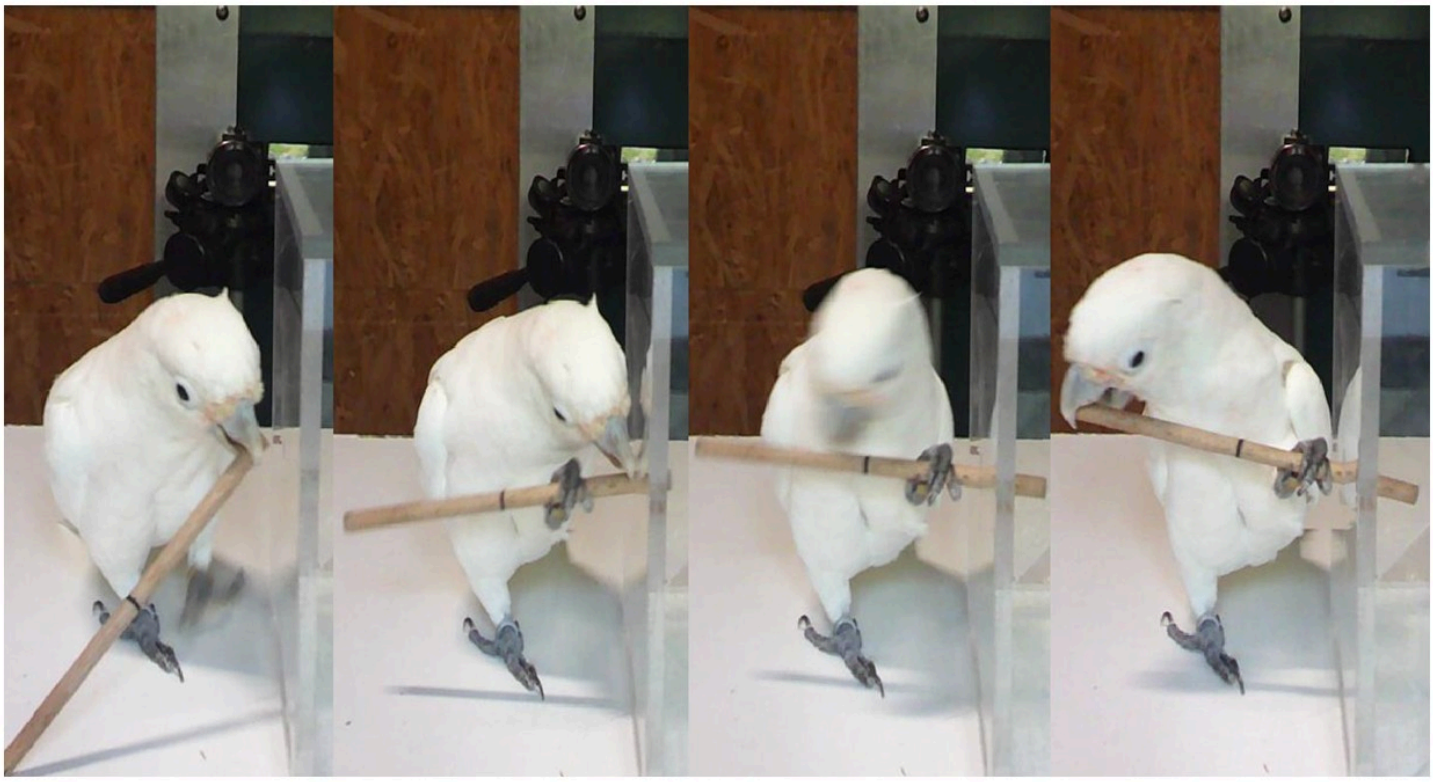


Figure 2

Step-by-step images demonstrating Zozo's foot insertion technique. After lifting one end of the stick with his beak, he moved the proximal end toward the opening. He then stabilized the stick with his foot near the beak grip and pushed it about 1–2 cm into the box. Simultaneously, Zozo shifted his head to the distal end of the stick and grasped it with his beak. Following establishment of the distal grip, he released the foot support and completed the insertion in one continuous beak motion.

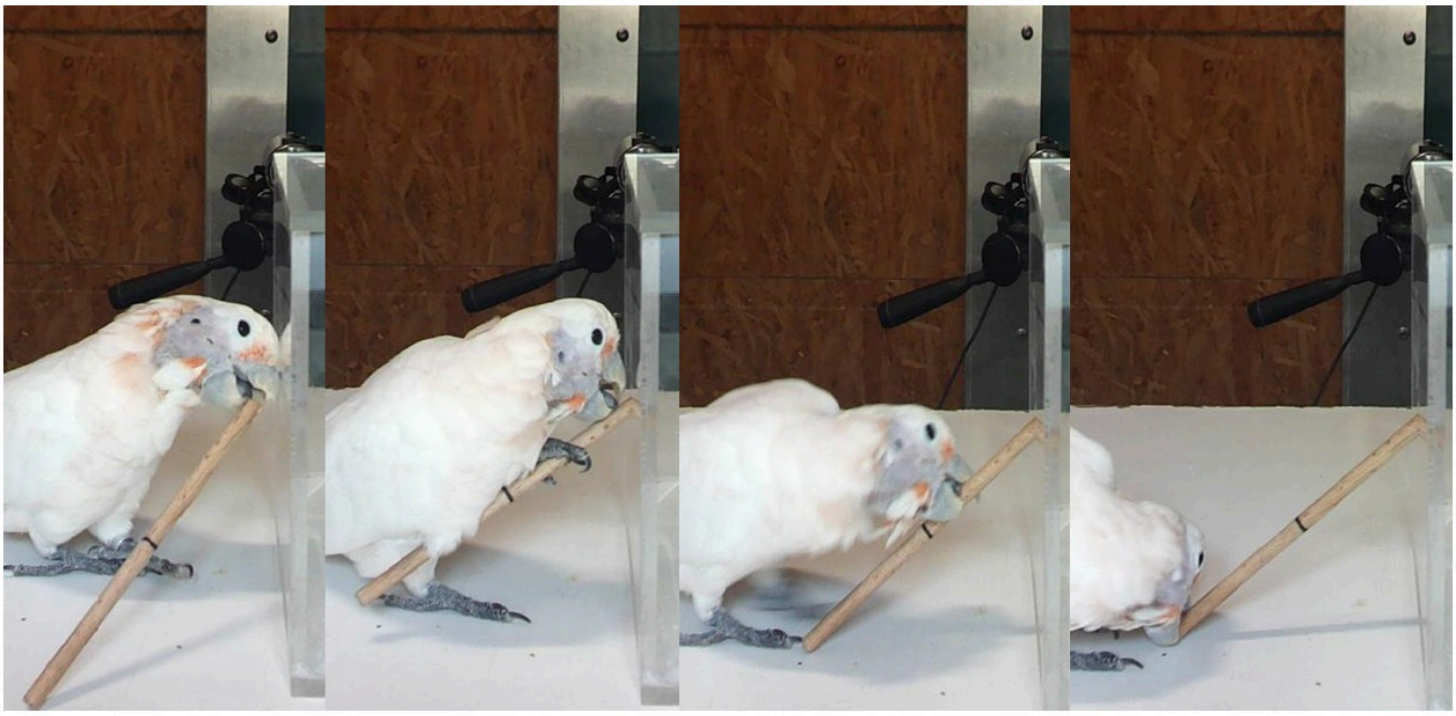


Figure 3

Step-by-step images illustrating Muppet's foot insertion technique. After lifting one end of the stick between his mandibles and bringing it near the entrance, Muppet stabilized the proximal end at the opening with the combined use of his beak and foot. Once the stick rested securely at the entrance, he maneuvered it downward using his beak, grasped the distal end between his mandibles, and completed the insertion with a final push.

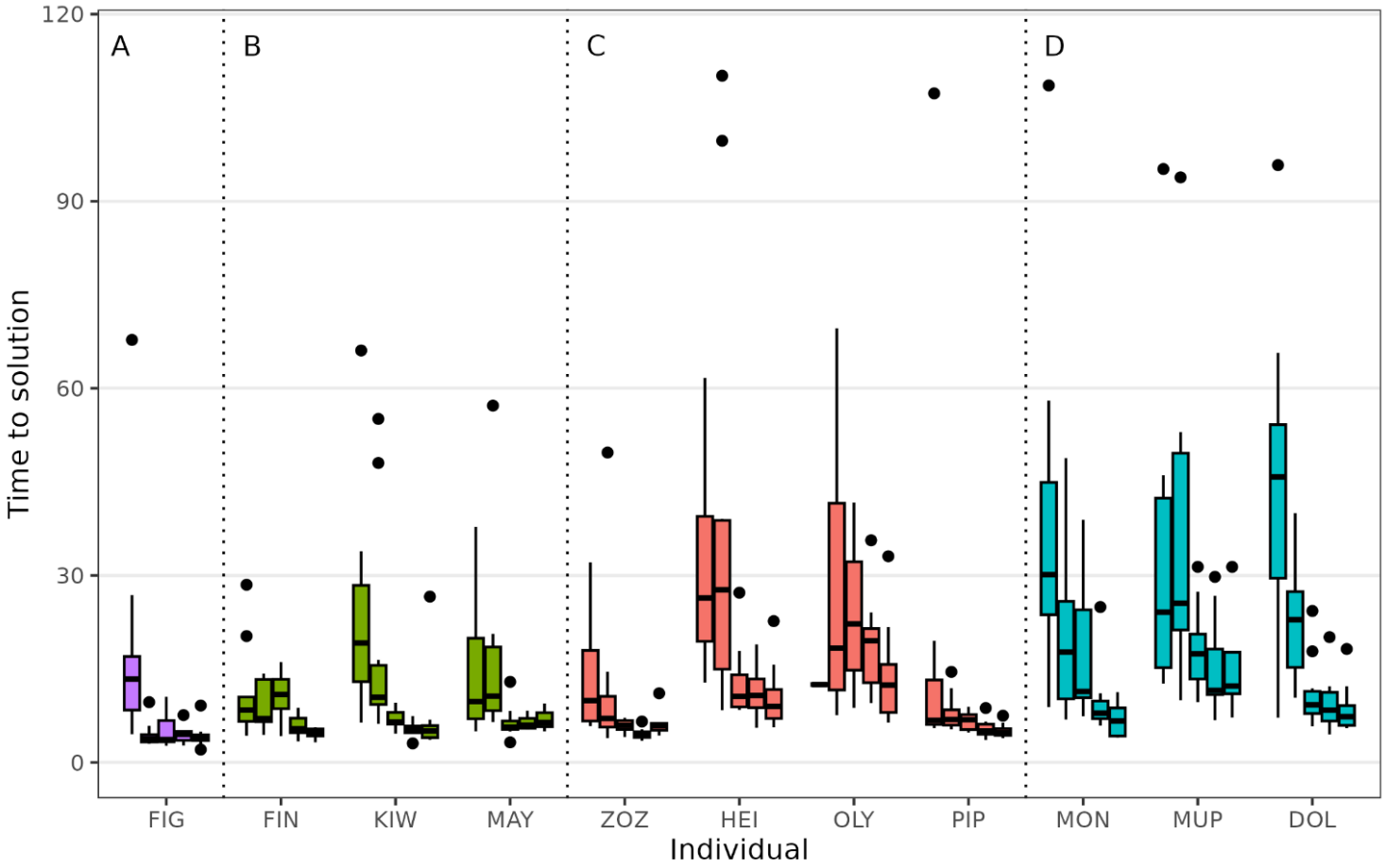


Figure 4

Technique groups with respective mean trial time. Plots visualizing the mean time (in seconds) of successfully finished trials per session per subject. Subjects grouped together by technique, shown here in colors (A=*Figaro's Technique*, B= *Needling*, C=*Foot Insertion*, D= *Entrance Securing*). No significant effect of Technique group was detected. For model summary see Supplementary xx.

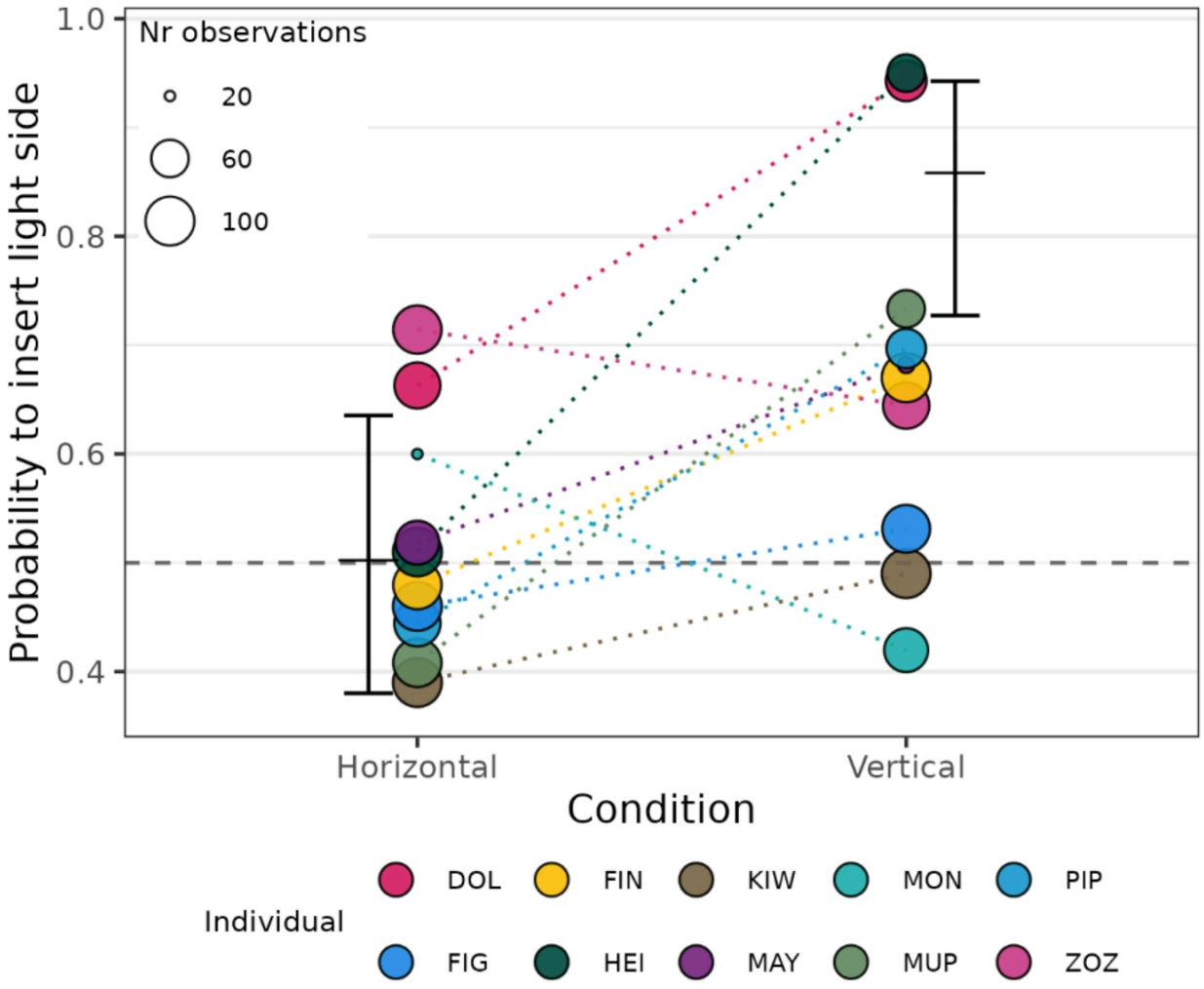


Figure 5

Plot showing the probability of light side completions (LS) for each subject for the two conditions horizontal (H) and vertical (V). Dashed line at 50% marks the expected level of LS-completions if choice were random. For model summary see Supplementary xx.

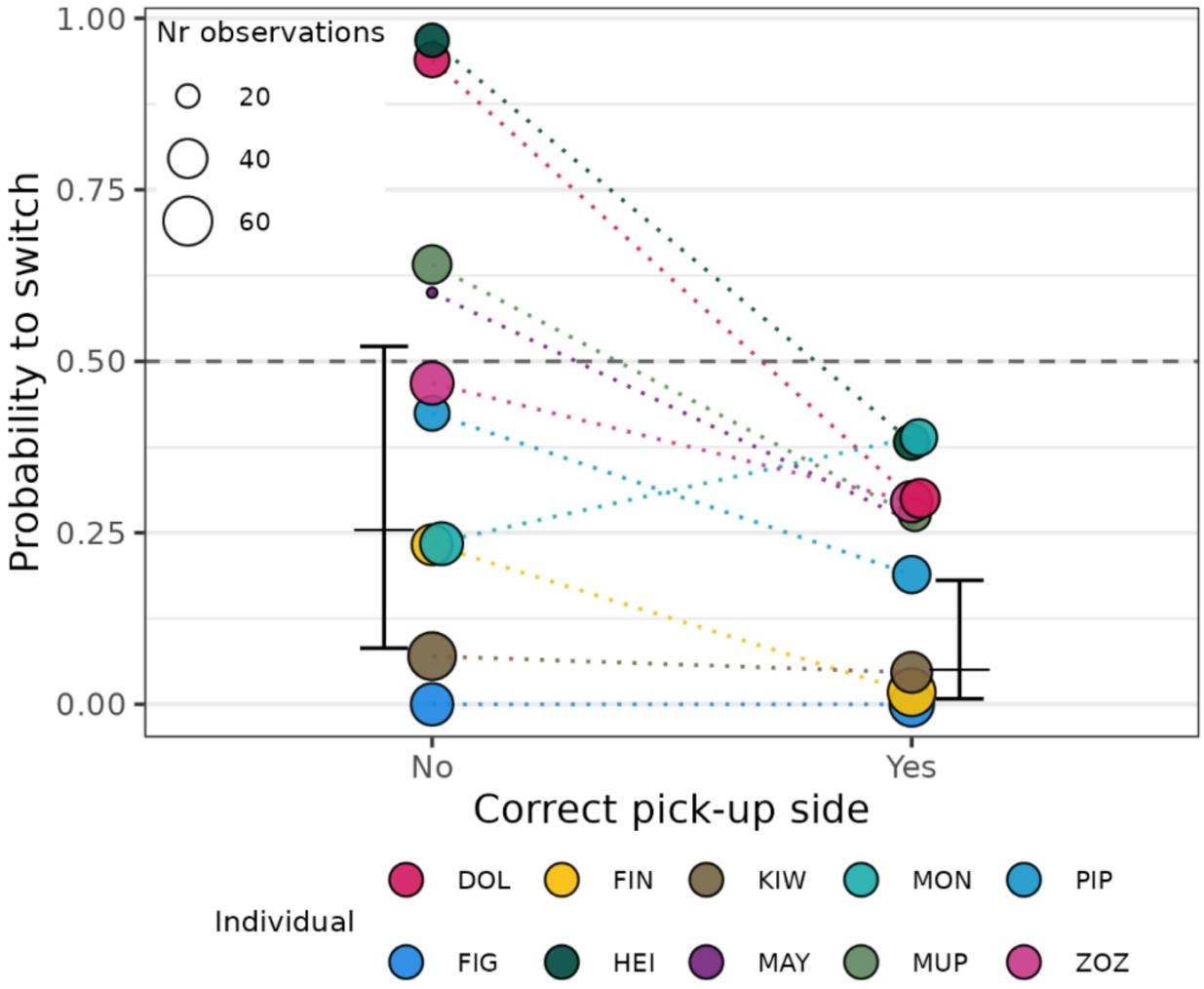


Figure 6

Plot showing the probability to switch stick sides. Birds were twice as likely to switch when the incorrect side was picked up first (in 156 out of 391 trials (39.9%)), than when the correct side was picked up first (in 74 out of 385 trials (19.2%)). For model summary see Supplementary xx.

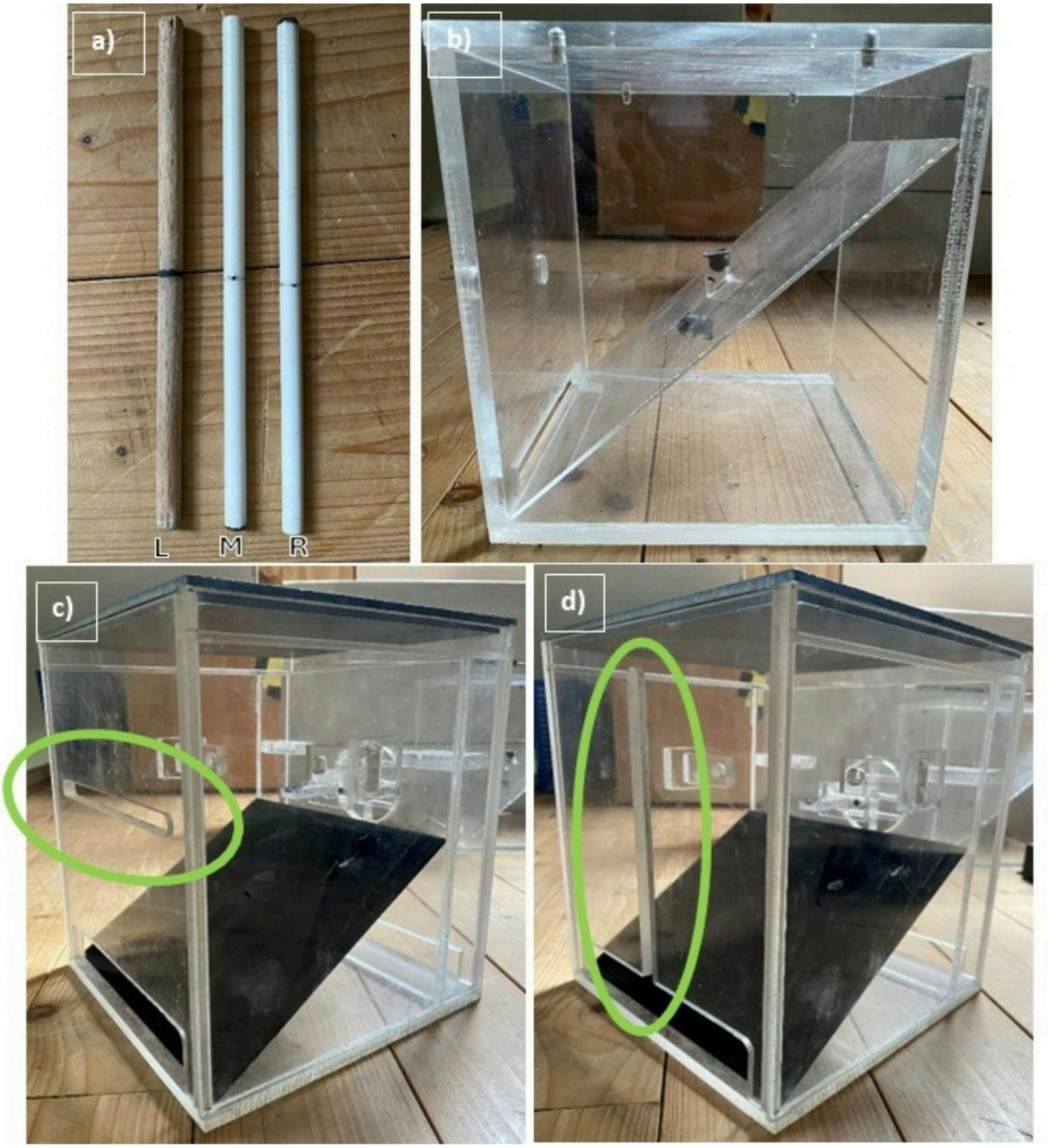


Figure 7

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.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

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