Short communication

String-pulling behaviour in a Harris's Hawk *Parabuteo unicinctus*

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Variations on the string-pull experiment have been presented to a variety of avian species. Here, we present the results of a basic vertical string-pull task with a Harris's Hawk *Parabuteo unicinctus*. A 2-year-old subject retrieved a shielded food reward within 8 min on each of eight trials and spontaneously used solving techniques similar to corvids and parrots. Our data contribute to the small body of literature on raptor cognition by showing that it may be within the realm of at least one bird of prey species to perform the string-pull task similarly to avian species renowned for their high cognitive abilities.

Keywords: avian cognition, bird of prey, problem solving, raptor.

For more than half a century, the string-pull task has been considered a reliable measure of avian problem-solving ability (e.g. Great Tits *Parus major* Vince 1956, finches *Carduelis* spp., Common Chaffinch *Fringilla coelebs*, Canaries *Serinus* spp. Vince 1958, 1961, Budgerigar *Melopsittacus undulatus*, Common Myna *Acridotheres tristis*, Western Jackdaw *Coloeus monedula*, Dücker & Rensch 1977, Northern Raven *Corvus corax*, Heinrich 1995, Heinrich & Bugnyar 2005, Grey Parrots *Psittacus erithacus*, Pepperberg 2004, Kea *Nestor notabilis*, Huber & Gajdon 2006, Werdenich & Huber 2006, Turquoise-fronted Amazon *Amazona aestiva*, Hyacinth Macaw *Anodorhynchus hyacinthinus* and Lear's Macaws *Anodorhynchus leari*, Schuck-Paim *et al.* 2009, New Caledonian Crows *Corvus moneduloides*, Taylor *et al.* 2010). In the basic task, a food reward is suspended from a perch by a string (Fig. 1) and the subject's behaviour is recorded. Although many bird species have been presented with variations of the string-pull task, prior to the current study, birds of prey had not been tested. As some raptor species rival parrot and raven species with respect to the relative sizes of their telencephalon (the avian forebrain, the area of higher cognitive functioning; Burish *et al.* 2004), we sought to provide preliminary string-pulling data for this group of birds.

The Harris's Hawk *Parabuteo unicinctus* (also known as the Bay-winged Hawk) was selected for this preliminary investigation because it shares an important feature with parrots and some corvids (two high-performing groups) that could be relevant to solving the task. Harris's Hawks are classified as social in that they hunt cooperatively (Bednarz 1988, Ellis *et al.* 1993) and engage in shared nest attendance among adults (Mader 1975). Likewise, parrots (e.g. Seibert 2006) and some corvids (e.g. American Crow *Corvus brachyrhynchos*, Knopf & Knopf 1983) are also classed as social. According to the Social Intelligence Hypothesis (Byrne & Whiten 1988), human intelligence may have been enhanced by the ability to learn from others, which resulted as a consequence of social living. Empirical work with non-human animals supports the relationship between sociality and intelligence (e.g. Reader & Laland 2002, Burish *et al.* 2004, for counter-evidence see Beauchamp & Fernández-Juric 2004). Without a non-social raptor species for comparison, it is impossible to draw definitive conclusions about the relevance of sociality to social raptors' cognitive abilities. Nevertheless, the common feature of sociality among Harris's Hawks, parrots and some corvids led us to predict that a Harris's Hawk's performance on the string-pull task might be similar to that observed in many parrots and corvids.

METHODS

subject

A 2-year-old male Harris's Hawk was the subject of the study. The Hawk was captive-bred at Coulson Harris'
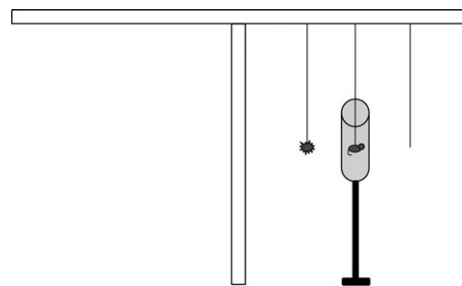

Figure 1. Diagram of baited string-pulling apparatus with clear plastic shield surrounding food reward. Diagram not drawn to scale.

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Hawks, a federally licensed raptor propagation facility in Louisiana, USA. After 18 months of being flown as a falconry bird, the Hawk was injured and spent 2 months at a raptor rehabilitation centre in northeast Georgia before the beginning of testing in November 2010. At the time of testing, the Hawk was housed in an outdoor primary chamber ($2.45 \times 3.66 \times 2.45$ m). The Hawk was fasted for 24 h prior to test days. Testing days were spaced at least 1 day apart.

Apparatus

All experiments were conducted in the Hawk's primary chamber. Three strings (0.5 cm diameter braided nylon cord, 60 cm in length, 23 cm apart) were suspended vertically from the primary perch. The test string was baited with a food reward (a previous frozen mouse of *c.* 25 g). One control string was baited with a pinecone of similar size (20 g), and the second control string was unbaited (Fig. 1). To prevent access to the bait from beneath, a clear plastic shield (45 cm; diameter 7.5 cm) was attached to a steel base as shown in Fig. 1. A Sony HandyCam mini-DV video camera mounted on a tripod 2 m from the apparatus recorded all trials.

EXPERIMENTAL PROCEDURE

Prior to first testing, the subject spent 3 h habituating to the recording equipment, shield and three unbaited strings suspended from the perch. Trials began by placing the Hawk on its perch. After starting the video camera, the experimenter baited the string, presented the bait to the Hawk, lowered it into the shield and then exited the chamber. Trials lasted 30 min and the subject was fed no less than 3 h following trials to maintain motivation during testing. The apparatus and recording equipment were removed from the enclosure after test trials. All procedures were approved by the institution's animal use committee (Approval #A2010-10199).

Data analysis

Videotaped trials were coded in THE OBSERVER XT (v. 7.0) using a coding scheme adapted from Werdenich and Huber's (2006) ethogram that included exploratory, effective and ineffective behaviours (see Table 1). An outside observer coded a random 2-min segment of video (11% of video footage). A Cohen's kappa coefficient of reliability was calculated using a behaviour matrix and a 'null' category for when one rater coded a behaviour when no behaviour was observed by the other rater (A.B. Kaufman, E.N. Colbert-White & R. Rosenthal unpubl. data). The coefficient of reliability was $\kappa = 0.73$, where > 0.75 is considered 'excellent' reliability (Cicchetti & Sparrow 1981). Without the three instances of null codes, reliability between raters increased to $\kappa = 0.91$.

Latency to solve was defined as the time from when the bait was lowered into the shield until it was grasped by foot or beak. Time spent gazing at the baited string was also recorded for each trial to provide a measure of the bird's attention to the task during each trial. Eye gaze was defined as the Hawk's head being oriented downward toward the apparatus for at least 3 s. The 3-s criterion was included in each instance of eye gaze. For example, if the Hawk continued to gaze at the apparatus for 4 s after the 3-s criterion was met, the gaze time would be recorded as 7 s. Eye gaze instances were tabulated and converted to a proportion of total trial time.

Table 1. Ethogram of behaviours observed during string-pull trials.

Behaviour	Description of action	Classification
Gaze (on or off)	Oriented toward baited string > 3 s	Exploratory
Approach (1)	Moves towards test string (from any distance)	Exploratory
Back-up (2)	Moves away from test string (to any distance)	Exploratory
Circle (3)	Moves body to opposite side of apparatus while gazing at baited string	Exploratory
Fly away from apparatus (4)	Flies out of camera view to perch on other side of enclose	Exploratory
Grab string (5)	Grabs baited string with beak (5a) or foot (5b)	Effective
Pull string (6)	Uses beak (6a) or foot (6b) to pull baited string in any direction	Effective
Release string (7)	Lets go of baited string from beak (7a) or foot (7b)	Effective
Walk string (8)	Holds baited string in beak (8a) or foot (8b) while hopping laterally across perch	Effective
Foot hold (9)	Secures baited string in foot and either holds or presses foot to perch	Effective
Grab reward (10)	Successfully retrieves bait with either beak (10a) or foot (10b)	Solve
Grab nothing (11)	Grabs for baited string, reward, or shield with beak (11a) or foot (11b) and misses	Ineffective
Grab shield (12)	Grab shield with foot	Ineffective
Tug string (13)	Short pulls at baited string with beak near knot; does not affect position of bait	Ineffective
Pull knot (14)	Bites and pulls up at baited string knot with beak	Ineffective
Other (15)	Other behaviour (e.g. loses balance on perch)	Other

RESULTS

Eight trials were conducted. Upon first presentation, the Hawk retrieved the mouse in 380.1 s; subsequent solve times ranged from 8.5 to 470.6 s (Fig. 2b). Interaction with a control string occurred only once (a bite at the unbaited string's knot during Trial 2), indicating a strong preference for the baited string.

As shown in Tables 1 and 2, the Hawk engaged in a variety of behavioural sequences to reach the bait. Early on, exploratory (e.g. circling the apparatus while looking at the bait) and ineffective (e.g. pulling the knot) behaviours were most common. For example, all 31 instances of pulling the knot appeared during the first two trials. As sessions went on, however, ineffective behaviours were replaced by effective behaviours such as pulling up the string. Table 2 provides the ratios of effective behaviours to total behaviours for all eight trials. Over time, inefficient behaviours were phased out as the Hawk
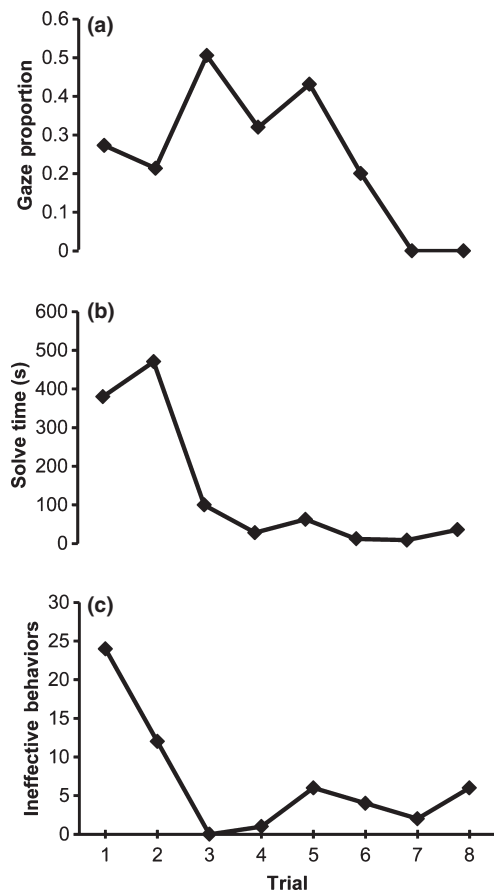

Figure 2. Increase in the Hawk's solving efficiency across trials depicted in three panels. Both the proportion of total time spent gazing at the apparatus (a) and total solve time (b) decreased across trials. The number of ineffective behaviours (c) also decreased across trials.

learned that manipulating the string was integral to retrieving the bait.

During Trials 4, 6, 7 and 8 the Hawk spontaneously engaged in sequences of pulling up the string with the beak or foot, anchoring the string with the beak or foot, then pulling up again with the beak or foot (Supporting Information Video Clip S1). The Hawk's beak and both feet were used interchangeably for all steps of the pull-anchoring sequences, as well as the final grasping of the mouse. During Trials 2 and 8, the subject engaged in a lateral side-step method of hopping across the perch with the string loosely held in the beak or foot until the bait was close enough to grasp. During Trials 1, 3 and 5, the Hawk retrieved the reward by grabbing the string with the beak or foot as close to the bait as possible, pulling up, and then extending the leg to grasp the bait with the foot.

The proportion of time spent gazing at the apparatus (Fig. 2a) and time to solution (Fig. 2b) decreased across trials. Although at least one ineffective behaviour (i.e. pulling the knot, grabbing nothing, grabbing the shield or tugging the string) occurred during all trials except Trials 3 and 6, the number of ineffective behaviours decreased over time (Fig. 2c). Overall, the trends shown in Fig. 2 demonstrated a clear learning curve, which was established after only a few trials.

DISCUSSION

This investigation provides the first empirical evidence that a member of a social raptor species can solve the string-pull task in similar time and with similar solving behaviours to some parrots and corvids. The test subject retrieved the food reward within 8 min of first viewing the problem, a time within some species' documented time to first solution (e.g. Northern Ravens, Heinrich 1995, Heinrich & Bugnyar 2005). Considerably faster first-solution times have been documented in Lear's Macaws (12 s, Schuck-Paim *et al.* 2009), New Caledonian Crows (6 s, Taylor *et al.* 2010) and Keas (9 s, Werdenich & Huber 2006). The method of solving was also similar, as the Hawk's spontaneous use of pull-anchoring and lateral side-stepping has been documented in other species (e.g. Heinrich 1995, Pepperberg 2004, Werdenich & Huber 2006).

Unlike some birds tested (e.g. Schuck-Paim *et al.* 2009), the Hawk immediately approached the apparatus and displayed little neophobia. In addition, we observed highly aggressive behaviour towards the apparatus, which to our knowledge has not been documented in other studies of string-pulling in birds. We attribute the aggressiveness and low levels of neophobia to the subject's prior experience with baited lures during falconry training, its predatory nature or a combination of the two.

We also attribute to the Hawk's predatory nature (which involves prey capture with the feet) its heavy reliance upon the feet for manipulating (i.e. grabbing

Table 2. Behavioural data for each trial. Number and letter codes were used to construct behavioural sequences. Gaze was coded as a state rather than event, and so was coded and timed as being 'on' or 'off'.

Trial	Behaviour sequence	Ratio of effective to total behaviours
1	4, 1, 2, 1, 1, 4, 1, 1, 14, 14, 2, 14, 14, 14, 14, 15, 14, 2, 2, 2, 1, 2, 14, 1, 2, 2, 1, 2, 1, 5a, 6a, 7a, 14, 14, 14, 14, 14, 15, 15, 14, 14, 14, 14, 14, 14, 14, 5a, 6a, 11b, 11b, 11b, 10b	0.09
2	1, 1, 14, 14, 4, 1, 3, 4, 1, 1, 14, 14, 14, 14, 14, 2, 3, 15, 14, 2, 1, 3, 4, 1, 15[a], 2, 2, 3, 2, 1, 12, 14, 14, 2, 12, 5b, 6b, 8b, 6b, 8b, 10a	0.12
3	1, 1, 2, 2, 2, 1, 2, 3, 3, 15, 1, 2, 5b, 15[b], 10a	0.07
4	1, 12, 5a, 6a, 7, 5a, 6a, 10b	0.63
5	1, 11a, 11a, 11a, 2, 1, 3, 12, 12, 5b, 6b, 11a, 6b, 10b	0.21
6	5b, 6b, 9, 5a, 6a, 7b 10b	0.86
7	12, 5b, 6b, 5a, 6a, 7b, 11b, 10b	0.63
8	5a, 6a, 7a, 5a, 6a, 7a, 5a, 6a, 7a, 5a, 6a, 7a, 5a, 6a, 7a, 5a, 6a, 7a, 2, 5a, 6a, 7a, 12, 5b, 6b, 9, 5a, 6a, 8a, 7a, 5a, 6a, 7, 8a, 9, 7, 10a	0.92

Because Gaze was coded as a state rather than an event, it is not included in the behaviour sequences. Instead, time spent gazing at the apparatus was recorded for each trial, which appears in Fig. 2(a). The ratio of effective behaviours to total behaviours was calculated by dividing the number of effective behaviours (Fig. 1) in a trial by the total number of behaviours coded for that trial. [a]Indicates the one instance in which the subject interacted with (i.e. bit knot) a control string. [b]Indicates subject fell off the perch momentarily after using the foot to grab the string very close to the location of the mouse.

and pulling) the string rather than simply stepping on it. Although parrots and corvids can also grasp with their feet, as Heinrich (1995) pointed out, in a review of string-pull results only Werdenich and Huber's (2006) study with Keas described grasping and pulling up on the string with the foot. However, this behaviour was scored only once in the first trial for two of their seven subjects. The other studies with parrots (e.g. Pepperberg 2004, Schuck-Paim *et al.* 2009) and corvids (e.g. Heinrich 1995, Heinrich & Bugnyar 2005, Huber & Gajdon 2006, Taylor *et al.* 2010) described no foot use beyond stepping.

We suggest that the Hawk's behaviour when presented with the string-pulling task could be explained as originating in species-typical behaviours of birds that use their feet during foraging. Altevogt (1953) described the tendency for species that use their feet during foraging (e.g. holding or grasping food items) to engage in reflexive grabbing behaviours. One reflexive grab could inadvertently lift the string and bait closer to the bird. Taylor *et al.* (2010) tested this hypothesis using a visually restrictive string-pulling apparatus with New Caledonian Crows. When subjects could not see the bait move as a result of their actions, performance decreased. According to those authors, the findings indicated that in New Caledonian Crows, string-pulling behaviour may indeed be better explained by operant principles (if an action brings the bait closer, repeat that action) than by positing the use of 'insight' or other reasoning processes. Nevertheless, we agree with those who consider the string-pull task to be an interesting measure of problem-solving ability in non-humans, and we consider all species' performance on the task to be worthy of attention.

Although Harris's Hawks, parrots and some corvids are social (in the sense specified above), the role sociality plays in their problem-solving ability cannot be determined from the current study. In a relevant series of investigations (Biondi *et al.* 2008), Chimango Caracaras *Milvago chimango* successfully solved a puzzle box problem. These neotropical raptors also demonstrated the ability to learn from conspecifics (Biondi *et al.* 2010), which the authors attributed to the species' 'gregarious' and congregative natural behaviour. Building on these promising results, non-social raptor species such as the Red-shouldered Hawk *Buteo lineatus* (Kerlinger 1989) should be tested to understand more completely the influence of sociality on raptors' cognitive abilities.

Cognitive research involving birds of prey is limited, despite findings that some species have forebrain homologues that rival those of parrots and corvids in terms of relative size (Burish *et al.* 2004), and that at least one species is capable of solving a puzzle box problem (Biondi *et al.* 2008). It is our hope that the results presented here will encourage others to explore further the cognitive abilities of raptors.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Video S1. This video illustrates two solving methods used by the Harris's Hawk. The first clip shows the pull-step-pull method; the second clip shows the lateral side-step method.