

Abstract concept formation in African grey parrots (*Psittacus erithacus*) on the basis of a low number of cues

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ABSTRACT

The formation of the concept of sameness is considered as a crucial cognitive ability which allows for other high cognitive functions in some species, e.g. humans. It is often operationalized as transfer of the matching rule to new stimuli in a matching-to-sample task. Animal species show great differences regarding the number of stimuli needed in training to be able to perform a full transfer to new stimuli. Not only apes appear to master this task, but also corvids among the birds were shown to reach a full transfer using only few stimuli. Using colour, shape and number stimuli in a matching-to-sample design, we tested four grey parrots for their ability to judge identity. Only a limited set of 8 stimulus cards were used in training. Pairs of “same” number stimuli were visually different thus allowing to be matched according to number of elements only. All four parrots successfully transferred to testing phases including testing with completely new stimuli and their performance did not drop with new stimuli. Including number stimuli invalidated some interpretations based on visual non-abstract processes and give evidence for formation of the concept of sameness.

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1. Introduction

One important sign of intelligence of a species is the capability to form complex abstract concepts. Abstract concepts differ from perceptual concepts which are based on generalization of perceptual features as well as from associative concepts based on learned associations of the stimuli with a common response or outcome. Abstract concepts involve learning of relations between stimuli based on rules (Katz et al., 2002, 2007). One of the most basic abstract (relational) concepts is the concept of sameness: the rule about identity (similarity) among stimuli (Katz et al., 2002; Wright and Katz, 2006), or, in other words, the ability to report that one stimulus is the same as another, irrespective of absolute properties of the objects (Zentall et al., 2008). This ability to classify stimulus sets as same or different is considered a basic cognitive skill upon which many other cognitive functions are based (Delius, 1994). The abstract concept of sameness is often studied using the matching-to-sample method (conditional discrimination), where a sample stimulus indicates which of two comparison stimuli is correct (Zentall et al., 2008). The formation of the concept of sameness is tested by employing new stimuli that have not been used for training in the matching-to-sample task. If an animal is as efficient at the first trial with completely new stimuli as in training, many recent authors conclude that it uses the concept of sameness, i.e.

that relational learning rather than item-specific learning occurred (Bodily et al., 2008; Cook, 2002; Katz et al., 2002, 2007; Lazareva and Wasserman, 2010; Mackintosh, 1988; Smith, 1993). Note however, that the terminology is used differently by some authors, as e.g. Thomas (1996) who mentions the concept of sameness in the frame of the “class concept learning”. He reserves the term “relational concept” to problems including conjunctive, disjunctive or conditional relationships.

While still remaining within the framework of abstract concept formation as defined above, we can distinguish varying degrees of complexity or abstraction when performing identity judgments. At the basal level, judgement can be based on simple physical similarity. At a more abstract level, members of a category are judged as identical. At the most advanced level, identity of abstract relations is judged. Species differ according to their capability to form sameness judgments of different levels of complexity (Thompson and Oden, 1996). The highest level of abstractness, termed judgement of relations between relations or analogical reasoning, is usually granted only to adult humans and animals trained in the use of symbols (Premack, 1978, 1983). Some authors argued that a design including judgement of relations between relations is the only reliable test of the concept of sameness, whereas the ability to perform and transfer matching, especially when based on visual identity, can be reached using non-abstract operations (Oden et al., 1988; Premack, 1978). We agree to the point that visual identity can provide alternative cues to successful solution to the task (but the matching rule). Therefore for our study we chose a design which reduced the probability that these alternative non-abstract

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strategies (e.g., choosing the more frequent versus the less frequent stimulus) could be used; namely including number stimuli which are matched according to number of elements irrespective of their visual characteristics.

Most matching-to-sample studies on non-human animals work with physically identical versus different images. Katz et al. (2002) and Wright and Katz (2006) showed that the probability of relational learning versus item-specific learning to occur and the speed with which the abstract concept of sameness is acquired in such studies is positively associated with the size of the training set. Three species of monkeys and birds (rhesus monkey, capuchin monkey, pigeon) formed this abstract concept only with large sets of items. Wright's (1997) finding of the ability of pigeons to form an abstract matching rule following training with the combinations of only 3 stimuli has not been demonstrated by earlier or later studies (e.g., Wright et al., 1988; Wright and Katz, 2006; Bodily et al., 2008). In contrast, chimpanzees were shown to learn more quickly and apply the concept of sameness to novel items following training with only two stimuli (Oden et al., 1988). Possibly, the number of items needed to form the concept of sameness in a simple matching-to-sample task can be seen as another measure of higher cognitive processing in a species, in addition to the level of similarity judgement achieved through tasks with increasing complexity. Learning of the abstract concept of sameness with the use of a small set of objects and after a relatively short training in matching-to-sample was documented in bottlenosed dolphins (Herman et al., 1989). However, here the dolphin, trained in acoustic symbolic communication previously, received instructions in the form of acoustic symbols about what action to perform on the (matching) object. Thus a cognitively more complex symbolic (acoustic) representation of stimuli might have occurred and facilitated correct responding. Some other criticism regarding the methodology in this study has been also raised (see Schusterman et al., 1993). Among other bird species, various corvids have shown to form the sameness concept relatively easily. The European jay transferred to line orientation matching after training the matching-to-sample procedure with three pairs of colour stimuli (Wilson et al., 1985). Another bird species that was studied with respect to the matching concept formation was the hooded crow (Smirnova et al., 2000). This species also required a relatively low number of training stimuli and combinations to learn the matching rule and transfer it successfully to new combinations and stimuli. More specifically, crows were trained successively and repeatedly to match according to colour, shape and number, while a minimum number of stimuli were used for each category—two for colour and shape and four for number where visually different cards with identical number of elements were to be matched. Additional two shape and four number stimuli were used in the first part of testing, where crows already showed efficient transfer of the matching rule. The number of trials required by the two successful crows to reach the criterion to proceed to the first part of testing was approximately the same as monkeys and pigeons needed to learn to respond correctly to all possible combinations of stimuli from an 8-item set in the study of Wright and Katz (2006) (but note that the methodology differed). However, unlike the monkeys and pigeons which did not transfer to new stimuli, crows performed high above the chance level in the transfer tests and performance on new items or combinations was not lower than on familiar items or combinations, despite such a limited set of training stimuli and limited combinations among stimuli (Smirnova et al., 2000).

We propose that besides corvids we can find other bird species with similar capabilities among psittacids. High intelligence of parrots was shown in studies on the grey parrot Alex, who was able to communicate using English labels about objects, activities and abstract concepts as colour, shape, material, and numbers including zero (Pepperberg, 1999). Using the labels “color”, “shape”,

and “matter”, he was also able to identify what characteristic in two objects is same or different (Pepperberg, 1987, 1999). His extraordinary high level of abstract concept formation could have been facilitated by his ability to use vocal label as symbols, in sense of Premack's (1978, 1983) above-mentioned presumption. Alex started learning the same/different concept after a decade of everyday intensive training to use human labels. The ability of grey parrots without such extensive symbolic training to form the same/different concept has not been tested so far.

We used methodology closely matching the one of Smirnova et al. (2000) to demonstrate that the grey parrot is another species besides humans, apes and hooded crows that has a tendency to form the sameness concept, even in tasks where other strategies could be effective (item-specific learning). The procedure is a matching to sample task where, however, sameness is not always represented by physical similarity. In a considerable part of training and a half of testing, a card with the same number of visually different arrays is the correct match. Whereas with the first two kinds of stimuli – Arabic numerals and colours – the cards are matched according to the visual characteristics of shape and colour, to solve the task with the numerical stimuli, the animal cannot rely on perception of visual identity, but has to be able to distinguish between quantities, and then match two identical quantities.

2. Material and methods

2.1. Subjects

Our subjects were four African grey parrots. These parrots were offspring of wild-born individuals and were hand-reared in our laboratory. They are probably two males (Shango, Titilayo) and two females (Tokunbo, Asabi). They were 2 years old at the beginning of the experiment. They were kept in cages of 120 cm × 115 cm × 75 cm either separately or in a pair which were placed in the laboratory room and allowed to fly around the room for about 2–3 h a day, depending on the presence of humans. Besides the experiment presented here, they were involved in the model/rival training with the aim to teach them Czech labels (Giret et al., 2010).

2.2. General procedure

The experiment was started in November 2005 and finished in April 2008. Trainers were students of the Faculty of Humanities, Charles University, Prague, who were trained in handling and interaction with parrots and in the experimental procedure. Training or testing took part several times a week and a session usually lasted 15–20 min (approx. 20–30 trials), but could be shorter depending upon the subject's willingness to pay attention. When the parrot refused to make a choice (by not moving or flying away) even after our repeated encouragement to do so, the session was terminated and the trial was repeated in the next session. Because parrots were used to interacting with humans, and such interaction was motivating for them, comparably or perhaps even more strongly than food reinforcing, the trials had the form of social interaction of the human experimenter with the parrot. The human encouraged the parrot to look at the cards, and praised it for giving a correct response. During one trial, the parrot was offered a tray of 45 × 20 cm with three cards of 10 × 10 cm. The sample card was placed in the middle and two stimuli cards were placed at each end of the tray on bowls of 9 cm in diameter. The stimulus card which matched the sample card in colour, shape or number, represented the correct answer and covered a reward placed in the bowl. Pieces of nuts or seeds were used as rewards. The tray was prepared outside of the visual field of the parrot. The experimenter presenting

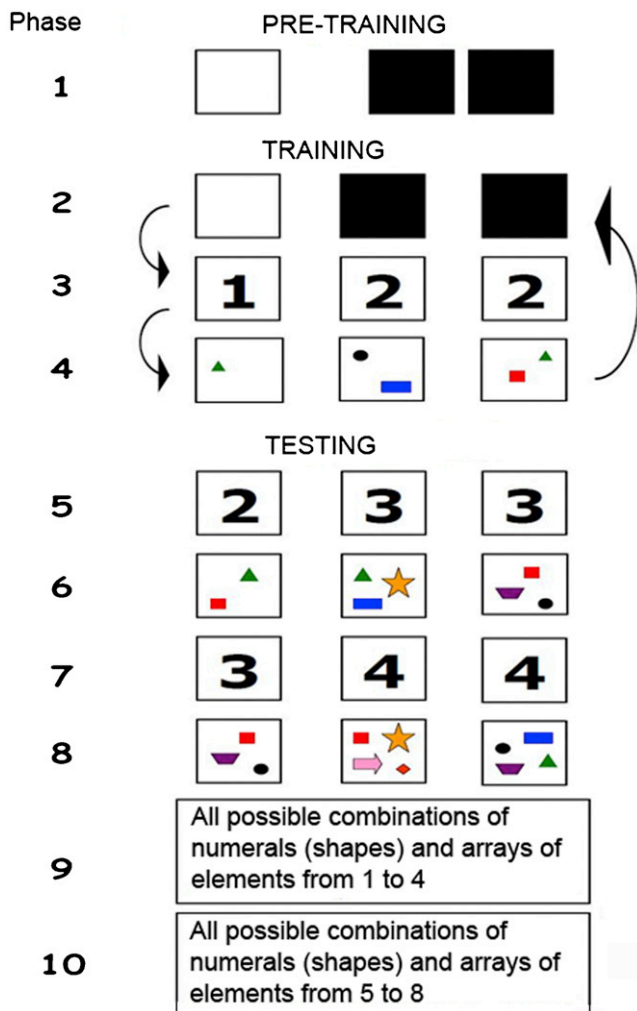


Fig. 1. Design of training and testing. Phases 2–4 were repeated cyclically until the birds were performing above 80% at the beginning of each of the phases.

the tray to the parrot directed his or her gaze at the sample card, to avoid providing other cues for the placement of the correct answer to the parrot. Subsequently, the parrot displaced one of the stimulus cards and uncovered a bowl which either contained or did not contain a reward depending on whether the subject chose the matching card.

2.3. Stimuli

The experimental stimuli and the sequence of training and testing phases were adopted from the study by Smirnova et al. (2000). For training, three categories of stimuli were used: colour, shape and number (see Fig. 1). Colour stimuli consisted of black and white cards. Shape stimuli consisted of cards with black Arabic numerals 1 and 2. As number stimuli, two cards with one element and two cards with two elements were prepared. The elements were geometrical shapes that differed in shape and colour both within and among the cards, so that two cards which were to be matched according to the number of elements were not visually identical. Stimuli from different categories were not combined.

For testing, only shape and number stimuli were used. In addition to cards already used in training, cards with Arabic numerals 3–4 were consecutively added as shape stimuli, and cards with 3–4 elements were added as number stimuli in the first part of testing (Phases 5–8; see Fig. 1). Phase 10 was comprised of new stimuli with Arabic numerals and numbers of elements 5–8. As for

Table 1
Number of trials to reach the criterion of 80% in 30 consecutive trials for each phase 1–8 and parrot.

Phase	Shango	Tokunbo	Asabi	Titilayo
1	354	381	67	130
2	1146	1415	205	193
3	245	159	339	74
4	80	334	82	30
2	177	32	198	30
3	368	553	43	55
4	54	140	31	167
2	233	30	91	83
3	46	342	71	45
4	132	131	35	97
2	98	30	30	37
3	46	38	43	37
4	47	118		63
2	33	34		52
3		87		40
4		30		35
2		30		51
3		30		30
4				30
2				30
5	30	48	30	30
6	47	30	30	30
7	30	30	30	30
8	72	35	30	39

training, two visually different cards for each number of elements were prepared, and served alternatively as the sample or the stimulus.

2.4. Training and testing

The experiment had 10 phases; an overview is shown in Fig. 1, and more details can be found in Smirnova et al. (2000). The combinations of the stimuli and sample cards in training were presented according to a pseudorandom schedule. Each training phase (Phases 1–4) was completed by reaching the criterion of 80% correct out of 30 subsequent trials. Phases 2 through 4 were cyclically repeated until the criterion of 80% correct answers was reached in 30 subsequent trials out of 50 first trials of each of the phases. Each of the following Phases 5–8 was finished when the same criterion was reached in 30 subsequent trials. Phases 9 and 10 were final testing phases which had 96 and 48 trials. In Phase 9, combinations used in training and new combinations of previously applied stimuli were tested. In Phase 10, new stimuli were introduced. In Phases 1–4, a corrective procedure was applied: if the parrot kept choosing the same side, the same trial was repeated until the parrot switched to the other correct side.

3. Results

Table 1 gives the number of trials that each parrot had in Phases 1–8 before reaching the criterion in each phase. Total number of trials in all training Phases 2–4 were 2705 for Shango, 3914 for Tokunbo, 1235 for Asabi and 1309 for Titilayo. (Compare with the two successful crows from Smirnova et al. (2000) which had 2360 and 3830 trials.) One of the parrots, Titilayo, was very close to reaching the criterion after only 382 trials. He reached 70% correctness in first 30 trials in Phase 3 and 80% in first 30 trials of Phase 4. But later his performance became very unbalanced, and it took nearly a thousand more trials for him to advance to testing.

Figs. 2–5 show the percentage of correct answers in first 30 trials in each consecutive phase. According to the sign test, 70% or more of correct trials is a significant result for a two-tailed test at a significance level of $\alpha = 0.05$. All test Phases (5–10) had strongly significant results (73–97% correct answers) except for two cases:

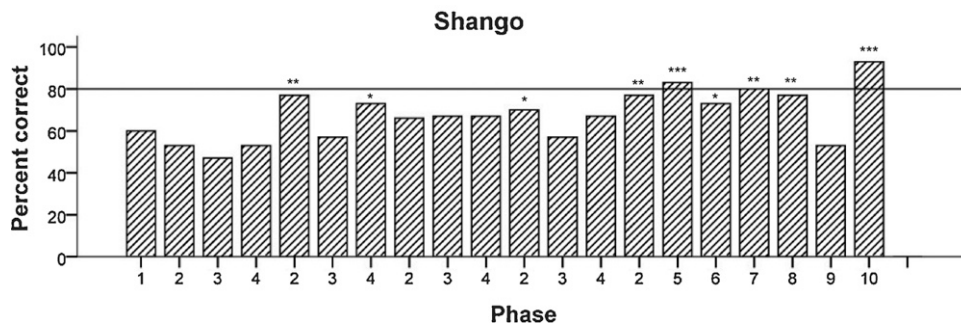


Fig. 2. The percentage of correct answers in first 30 trials in each consecutive phase for Shango. * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

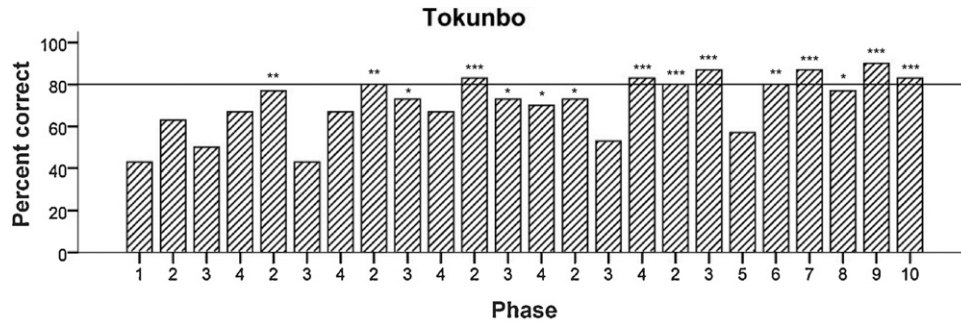


Fig. 3. The percentage of correct answers in first 30 trials in each consecutive phase for Tokunbo. * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

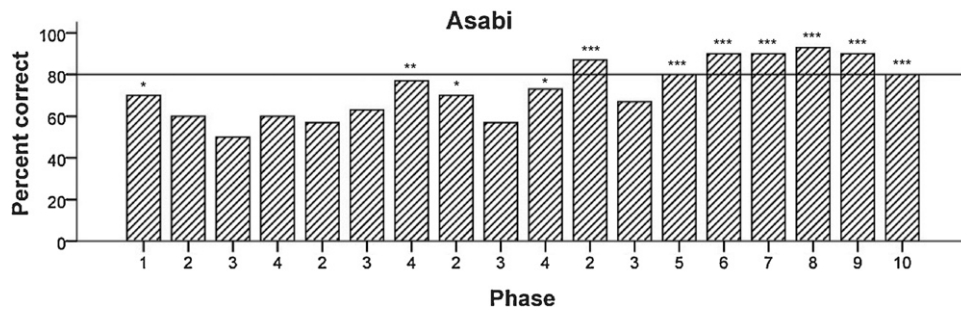


Fig. 4. The percentage of correct answers in first 30 trials in each consecutive phase for Asabi. * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

Phase 5 for Tokunbo and Phase 9 for Shango. Phase 9 was comprised of old (48 trials) and new (48 trials) combinations of familiar stimuli. Titilayo was significantly better at new combinations following a two-proportion Z-test. The other three birds did not show a difference in efficiency in the new and familiar combinations (Table 2).

Phase 10 tested entirely new stimuli in an analogical design as Phase 9. Table 3 shows the difference in performance between Phase 9 (96 trials) and Phase 10 (48 trials). All tested birds were

comparably efficient with new stimuli as with familiar stimuli according to a two-proportion Z-test, reaching 77–90% correct trials in these two final testing phases (remember that the limit for performing above chance level is 70%).

Three out of 4 parrots were not more successful with shape stimuli than with numerical stimuli in Phases 9 and 10 (Table 4). Titilayo's performance was lower with numbers than with numeral shapes. Even his lowest performance, however, stays above the chance level in a one-tailed test (sign test: $p = 0.032$). Moreover,

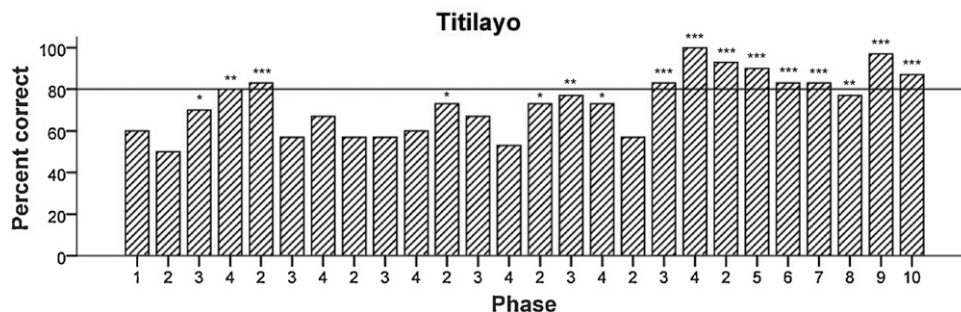


Fig. 5. The percentage of correct answers in first 30 trials in each consecutive phase for Titilayo. * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

Table 2
Difference between efficiency of parrots in familiar and new combinations of familiar stimuli in Phase 9.

Subject	Familiar combinations efficiency (in %)	New combinations efficiency (in %)	<i>p</i>
Shango	83	71	0.166
Tokunbo	85	92	0.285
Asabi	90	88	0.755
Titilayo	79	94	0.034*

* $p < 0.05$.

Table 3
Difference between efficiency of parrots in Phases 9 and 10.

Subject	Efficiency in phase 9 (in %)	Efficiency in phase 10 (in %)	<i>p</i>
Shango	77	90	0.059
Tokunbo	89	77	0.061
Asabi	89	81	0.190
Titilayo	86	83	0.635

when we looked at Titilayo's performance in Phase 10 in more detail, we found that all of his 7 mistakes concerned trials with the highest number 8. Whereas he was right in only 5 out of 12 trials including number 8, he was right in all 12 trials including only numbers 5–7. Therefore his failure might not have been due to his inability to match same numbers of arrays, or more generally, an inability to match two visually non-identical stimuli that only resemble in some abstract characteristic, but more specifically in his inability to process the highest number eight.

4. Discussion

All four tested grey parrots were able to learn the abstract matching concept relatively quickly based on a limited set of stimuli. Their performances were comparable to that of hooded crows (Smirnova et al., 2000).

The design of the study focused on a small set of training stimuli and combinations and thus rather reinforced the tendency to form non-abstract "if-then" rules or to learn configural patterns of stimuli, i.e. learn item-specific associations instead of forming an abstract matching-concept. However, all four parrots were able to transform the matching rule in testing phases with new stimuli and combinations. As they were immediately able to perform successfully in Phases 5–8 where new stimuli were added, we can assume that they have already formed the concept of sameness during training with only 8 stimuli and 6 combinations. Moreover, Titilayo performed highly above chance level already at the beginning of (first repetition of) Phase 3 and especially Phase 4. This seems to indicate that, first, he may have formed the matching concept based on only 2 stimuli (the black and white cards), and second, that this bird was able to transform the matching rule learned with 2 combinations of 4 visual stimuli from Phases 2 and 3 to a very different category of stimuli, where stimuli were to be matched according to the number of elements (Phase 4). Phases 5–8, as well as Phase 9 which introduced new combinations of old stimuli, were not

Table 4
Difference of efficiency of parrots in visual (shape) and numerical (number of arrays) trials in Phases 9 and 10.

	Efficiency phase 9, shape	Efficiency phase 9, number	<i>p</i>	Efficiency phase 10, shape	Efficiency phase 10, number	<i>p</i>
Shango	77	77	>0.999	92	87	0.572
Tokunbo	83	94	0.091	79	75	0.742
Asabi	88	90	0.754	88	75	0.246
Titilayo	90	83	0.316	96	71	0.020*

* $p < 0.05$.

reliable tests of the abstract concept formation because "if-then" rules possibly learned in previous phases could have facilitated correct responding. However, Phase 10, which included only novel stimuli, represented a reliable test of transfer of the learned abstract rule. This phase was successfully mastered by all tested parrots, with the efficiency being high above chance level and not statistically different from efficiency in the previous phase.

Grey parrots were not only able to match cards with identical visual stimuli, Arabic numerals, but they were also able to match visually (in shapes and colours of elements) different cards according to the number of elements present on the card. Previous research (Äin et al., 2009; Koehler, 1950; Pepperberg, 1994; Pepperberg and Gordon, 2005) already showed that grey parrots are able to process numbers up to at least 6. In our experiment, 5–8 elements were correctly processed without training within the matching-to-sample design by three parrots, and one parrot had a specific problem with trials involving number 8. These results cannot be interpreted as evidence that the parrots count up to 8. A more complex design including more trials for differential testing of the processing of each number would be necessary to make such a conclusion.

However, we proposed that the requirement of comparing stimuli which do not match in any other criterion but number of elements made the matching task more difficult as it ruled out simple conditioned processing, e.g. based on "old" versus "new" or "familiar" versus "unfamiliar", i.e. the relative number of times the animals see stimulus A versus the number of times they see the stimulus B (as was proposed by Premack, 1983), and thus strengthened the interpretation of abstract concept formation. On the other hand, we do not assume to have achieved a level of judgement of relations between relations as defined by Thompson and Oden (1996) in our subjects, as research of number processing shows that low numbers can be processed at a peripheral sensory level to a substantial degree (Trick and Pylyshyn, 1994) and in addition, that non-numerical visual cues are often successfully used to infer quantities (Al Äin et al., 2009). Additional studies are therefore needed to provide a test for the ability to judge relations between relations in grey parrots.

Previous work by Pepperberg (1987, 1999) with the grey parrot Alex already showed that this bird was able to use the abstract concept of sameness. Moreover, he was able to use his capability to communicate with symbolic vocal labels to identify dimensions which were same or different in an array of objects. According to Premack (1978, 1983), this higher level of abstract concept formation is restricted to symbolically communicating animals. Our parrots were unsuccessful in human label acquisition (for possible reasons see Giret et al., 2010). They were still able to show higher cognitive processing compared to some other species (e.g. pigeons, monkeys) by learning the concept of sameness through the matching-to-sample task with relatively few stimuli of both visual and numerical kind.

Our research brings new evidence of high cognitive skills in grey parrots, comparable to those found in corvids as well as in some of the most intelligent mammals. According to the social intelligence hypothesis (Humphrey, 1976; Marler, 1996; Emery and Clayton, 2004) species with complex social structure evolve better cognitive

skills to less social species. Social life of the grey parrot is similar to the life of some corvids, with gathering into large roosts for night, spreading into smaller groups to forage during the daytime, and forming long-term monogamous and territorial pair-bonds. Social complexity within the monogamous pair as well as within larger groups can be expected (Farabaugh and Dooling, 1996; Bradbury, 2003), although this topic is very little studied as a consequence of extreme mobility of the species and habitat in political unstable countries. Therefore, we need much more research to be able to speculate about the functions of particular high cognitive skills in this species.

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References

- Āin, S.A., Giret, N., Grand, M., Kreutzer, M., Bovet, D., 2009. The discrimination of discrete and continuous amounts in African grey parrots (*Psittacus erithacus*). *Anim. Cogn.* 12, 145–154.
- Bodily, K.D., Katz, J.S., Wright, A.A., 2008. Matching-to-sample abstract-concept learning by pigeons. *J. Exp. Psychol. Anim. Behav. Process.* 34, 178–184.
- Bradbury, J.W., 2003. Vocal communication in wild parrots. In: de Waal, F.B.M., Tyack, P.L. (Eds.), *Animal Social Complexity: Intelligence, Culture, and Individualized Societies*. Harvard University Press, Cambridge, MA, pp. 293–316.
- Cook, R.G., 2002. Same-different concept formation in pigeons. In: Bekoff, M., Allen, C., Burghardt, G.M. (Eds.), *The Cognitive Animal: Empirical and Theoretical Perspectives on Animal Cognition*. MIT Press, Cambridge, MA, pp. 229–237.
- Delius, J.D., 1994. Comparative cognition of identity. In: Bertelson, P., Eelen, P. (Eds.), *International Perspectives on Psychological Science, Vol. 1: Leading Theme*. Lawrence Erlbaum, Hillsdale, NJ, pp. 25–40.
- Emery, N.J., Clayton, N.S., 2004. The mentality of crows: convergent evolution of intelligence in corvids and apes. *Science* 306, 1903–1907.
- Farabaugh, S.M., Dooling, R.J., 1996. Acoustic communication parrots: laboratory field studies of Budgerigars *Melopsittacus undulatus*. In: Kroodsma, D.E., Miller, E.H. (Eds.), *Ecology and Evolution of Acoustic Communication in Birds*. Cornell University Press, Ithaca, NY, pp. 97–117.
- Giret, N., Péron, F., Lindová, J., Tichotová, L., Nagle, L., Kreutzer, M., Tymr, F., Bovet, D., 2010. Referential learning of French and Czech labels in African grey parrots (*Psittacus erithacus*): different methods yield contrasting results. *Behav. Process.* 85, 90–98.
- Herman, L.M., Hovancik, J.R., Gory, J.D., Bradshaw, G.L., 1989. Generalization of visual matching by a bottlenosed dolphin: evidence for invariance of cognitive performance with visual and auditory materials. *J. Exp. Psychol. Anim. Behav. Process.* 15, 124–136.
- Humphrey, N.K., 1976. The social fiction of intellect. In: Bateson, P.P.G., Hinde, R.A. (Eds.), *Growing Points in Ethology*. Cambridge University Press, Cambridge, pp. 303–317.
- Katz, J.S., Wright, A.A., Bachevalier, J., 2002. Mechanisms of same/different abstract-concept learning by rhesus monkeys (*Macaca mulatta*). *J. Exp. Psychol. Anim. Behav. Process.* 28, 358–368.
- Katz, J.S., Wright, A.A., Bodily, K.D., 2007. Issues in the comparative cognition of abstract-concept learning. *Comp. Cogn. Behav. Rev.* 2, 79–92.
- Koehler, O., 1950. The ability of birds to 'count'. *Bull. Anim. Behav. Soc.* 9, 41–45.
- Lazareva, O.F., Wasserman, E.A., 2010. Category learning and concept learning in birds. In: Mareschal, D., Quinn, P.C., Lea, S.E.G. (Eds.), *The Making of Human Concepts*. Oxford University Press, New York, pp. 151–172.
- Mackintosh, N.J., 1988. Approaches to the study of animal intelligence. *Br. J. Psychol.* 79, 509–525.
- Marler, P.K., 1996. Are primates smarter than birds? In: Nolan, V., Ketterson, E.D. (Eds.), *Current Ornithology*. Plenum Press, New York, pp. 1–32.
- Oden, D.L., Thompson, R.K.R., Premack, D., 1988. Spontaneous transfer of matching by infant chimpanzees (*Pan troglodytes*). *J. Exp. Psychol. Anim. Behav. Process.* 14, 140–145.
- Pepperberg, I.M., 1987. Acquisition of the same/different concept by an African Grey parrot (*Psittacus erithacus*) learning with respect to categories of color, shape, and material. *Anim. Learn. Behav.* 15, 423–432.
- Pepperberg, I.M., 1994. Numerical competence in an African gray parrot (*Psittacus erithacus*). *J. Comp. Psychol.* 108, 36–44.
- Pepperberg, I.M., 1999. *The Alex Studies*. Harvard University Press, Cambridge, MA.
- Pepperberg, I.M., Gordon, J.D., 2005. Number comprehension by a grey parrot (*Psittacus erithacus*), including a zero-like concept. *J. Comp. Psychol.* 119, 197–209.
- Premack, D., 1978. On the abstractness of human concepts: why it would be difficult to talk to a pigeon. In: Hulse, S., Fowler, H., Honig, W.K. (Eds.), *Cognitive processes in animal behavior*. Erlbaum, Hillsdale, NJ, pp. 423–451.
- Premack, D., 1983. The codes of man and beast. *Behav. Brain Sci.* 6, 125–137.
- Schusterman, R.J., Gisiner, R., Grimm, B.G., Hanggi, E.B., 1993. Behavioral control by exclusion and attempts at establishing semanticity in marine mammals using matching-to-sample paradigms. In: Roitblat, H.L., Herman, L.M., Nachtigall, P. (Eds.), *Language and Communication: Comparative Perspectives*. Erlbaum, Hillsdale, NJ, pp. 249–275.
- Smirnova, A.A., Lazareva, O.F., Zorina, Z.A., 2000. Use of number by crows: investigation by matching and oddity learning. *J. Exp. Anal. Behav.* 73, 163–176.
- Smith, L.B., 1993. The concept of same. In: Reese, H.W. (Ed.), *Adv. Child Dev. Behav.* 24, 215–252.
- Thomas, R.K., 1996. Investigating cognitive abilities in animals: unrealized potential. *Cogn. Brain Res.* 3, 157–166.
- Thompson, R.K.R., Oden, D.L., 1996. A profound disparity revisited: perception and judgment of abstract identity relations by chimpanzees, human infants, and monkeys. *Behav. Process.* 35, 149–161.
- Trick, L.M., Pylyshyn, Z.W., 1994. Why are small and large numbers enumerated differently? A limited-capacity preattentive stage in vision. *Psychol. Rev.* 101, 80–102.
- Wilson, B., Mackintosh, N.J., Boakes, R.A., 1985. Transfer of relational rules in matching and oddity learning by pigeons and corvids. *Quart. J. Exp. Psychol. B Comp. Physiol. Psychol.* 37, 313–332.
- Wright, A.A., 1997. Concept learning and learning strategies. *Psychol. Sci.* 8, 119–123.
- Wright, A.A., Katz, J.S., 2006. Mechanisms of same/different concept learning in primates and avians. *Behav. Process.* 72, 234–254.
- Wright, A.A., Cook, R.G., Rivera, J.J., Sands, S.F., Delius, J.D., 1988. Concept learning by pigeons: matching to sample with trial-unique video picture stimuli. *Anim. Learn. Behav.* 16, 436–444.
- Zentall, T.R., Wasserman, E.A., Lazareva, O.F., Thompson, R.K.R., Rottermann, M.J., 2008. Concept learning in animals. *Comp. Cogn. Behav. Rev.* 3, 13–45.