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Pigeons (*Columba livia*) Learn a Four-Item List by Trial and Error

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The aim of the current study was to assess whether pigeons could acquire a four-item list by trial and error. Pigeons received either extensive list training prior to being tested on a novel four-item list (i.e., the full-training group) or very limited training (i.e., the limited-training group). Specifically, subjects in the full-training group were trained to acquire a large set of two-item lists by trial and error, then a large set of three-item lists, and finally a large set of four-item lists. In addition, within each set, the number of training phases was gradually reduced. In contrast, the limited-training group were trained on a single four-item list prior to testing. Only one of the eight subjects (12.5%) in the limited-training group learned the novel four-item list. In contrast, all five subjects (100%) in the full-training group learned the novel four-item list. We suggest that the difference between groups reflects the fact that subjects in the full-training group acquired a learning set over the course of their extensive training. The current study is the first to demonstrate pigeons can learn a four-item list without phased training.

Keywords: serial-order task, simultaneous chain, learning set, pigeon

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Several decades ago Macphail (1985) proposed the null hypothesis. Macphail (1985) made the dramatic claim that there are no differences, neither qualitative nor quantitative, in intelligence across nonhuman species. In this context, a qualitative difference between species is the ". . . possession by one species of a mechanism that is absent in another," and a quantitative difference is defined as one species using ". . . a mechanism or mechanisms common to both species more efficiently than the other" (Macphail, 1985, p. 38). According to Macphail (1985), when differences between two species on a task are observed, the difference should at first be ascribed to what Bitterman (1965) referred to as a contextual variable. That is, one should assume that a noncognitive factor is responsible for the observed differences in performance between species.

The matching concept in pigeons is a classic example of the profound impact contextual variables can have on the performance of a particular species. Indeed, at a time when a number of researchers were having great difficulty demonstrating the matching concept in pigeons (Cumming & Berryman, 1961; Farthing & Opuda, 1974; Holmes, 1979), D'Amato, Salmon, and Colombo (1985) had little difficulty demonstrating it in monkeys. It was not until much later that two procedural variables (the fixed response requirement and number of training stimuli) were identified as having a critical influence on the pigeons' performance (Colombo, Cottle, & Frost, 2003; Wright, 1997). When these contextual variables were accounted for, pigeons displayed clear evidence of a matching concept.

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Another ability for which pigeons were once thought to come up short is responding in serial order (D'Amato, 1991; Scarf & Colombo, 2008, 2018; Terrace, 1993). The training task itself is relatively simple. On the serial-order task, the subject is presented with a list consisting of *n* number of simultaneously displayed items. The subject's task is to respond to each item of the list in a prescribed order. For ease of exposition, we refer to the items in a list with letters of the alphabet and the order in which they should be pressed with an arrow. Thus, the order of responses to a list of four items is shown as A → B → C → D. After reaching a prespecified performance criterion, the representation underlying a subject's performance is tapped by administering the pairwise test. The test consists of presenting subjects with all possible pairs of items that can be derived from the training list. On a four-item list, six pairs can be generated (AB, AC, AD, BC, BD, and CD). Monkeys perform well across all pairs in that they respond to the items of a pair in the order in which they appeared in the original list (D'Amato & Colombo, 1988). When presented with pair BC, for example, monkeys will first respond to B and then to C. In contrast, pigeons perform well on pairs that contain either the first or the last item (AB, AC, AD, BD, and CD), but at chance on the internal pair (BC) (Straub & Terrace, 1981). The pigeons' poor performance on pair BC was attributed to their failure to form a representation of the list (D'Amato, 1991; Terrace, 1993). Conversely, based on their success on the internal pair, monkeys were purported to form a representation of the list during training (D'Amato & Colombo, 1988). Based on these and other data, Terrace, Chen, and Newman (1995) argued that "the cognitive processes a pigeon and a monkey bring to bear on mastering a list reveal a major weakness in Macphail's (1985) null hypothesis" (p. 172).

Rather than rejecting the null hypothesis, Scarf and Colombo (2010b) investigated whether pigeons' poor performance on the internal pair was due to a contextual variable. Specifically, they investigated whether the sudden contextual change that a pigeon

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experiences when transferred from the four-item training list to the pairwise test might account for their poor performance on the critical internal pair. Keep in mind that performance on each of the pairs in the pairwise test is based on a very small number of trials. To counter this, Scarf and Colombo (2010b) trained a group of pigeons on a four-item list and, after reaching criterion, trained them to a criterion on just the BC pair. To control for learning effects, half of the birds were tested on a BC+ pair and half on a BC− pair. On the BC+ pair, subjects were reinforced when they pecked the items in the order true to that of the original sequence (B → C). In contrast, on the BC− pair, subjects were reinforced for pecking the items in the order opposite to that learned in the original sequence (C → B). Consistent with the view that pigeons, much like monkeys, form a representation of the list during training, subjects presented with the BC+ pair reached criterion in markedly fewer trials than the subjects presented with the BC− pair (Scarf & Colombo, 2010b).

More recently, the similarities between pigeons' and monkeys' performance on the serial-order task has been extended to the knowledge of the ordinal position of list items (Chen, Swartz, & Terrace, 1997; Harris, Beran, & Washburn, 2007; Scarf & Colombo, 2011), the ability to plan future responses (Beran, Pate, Washburn, & Rumbaugh, 2004; Scarf & Colombo, 2010a; Scarf, Danly, Morgan, Colombo, & Terrace, 2011; Scarf, Terrace, & Colombo, 2011), and the acquisition of abstract numerical concepts (Brannon & Terrace, 1998, 2002; Güntürkün, Ströckens, Scarf, & Colombo, 2017; Scarf, Hayne, & Colombo, 2011). In each instance, the performance of pigeons and monkeys is largely indistinguishable.

There is, however, one ability that pigeons have not yet demonstrated, that is, the ability to learn a list by trial and error without shaping. Training an animal on a single four-item list typically involves multiple shaping phases. For example, Phase 1 involves presenting subjects with just the first item (A) and rewarding them for responding to it. In Phase 2, subjects are presented with items A and B, with reinforcement contingent upon them responding to the items in the order A → B. In a similar manner, Phase 3 involves presenting subjects with items A, B, and C, and Phase 4 involves presenting them with all four items. Although early studies with monkeys and pigeons followed this successive-phase approach (D'Amato & Colombo, 1988; Straub & Terrace, 1981), Swartz, Chen, and Terrace (1991, 2000) have shown that, with exposure to multiple lists, monkeys can eventually learn to solve a four-item list when presented with all four items from the start of training. In other words, with extensive list experience, monkeys can learn to solve a four-item list by trial and error (Swartz et al., 1991, 2000; Terrace, Son, & Brannon, 2003).

The primary aim of the current study was to assess whether pigeons could also learn to solve a four-item list by trial and error. Following Swartz et al. (1991, 2000), we first trained subjects to acquire a large set of two-item lists via trial and error, then a large set of three-item lists, and finally a large set of four-item lists. In addition, within each set, we gradually reduced the number of shaping phases. To assess whether this stepwise approach was necessary in order for pigeons to learn a four-item list by trial and error, we also trained a group of pigeons using a limited number of training lists. Based on the learning-set literature, (Harlow, 1949; Hodos, 1970; Zeigler, 1961) we hypothesized that when tasked with learning a four-item list by trial and error, subjects in the full-training group would successfully acquire the list, whereas subjects in the limited-training group would fare poorly, and it is likely that their response would extinguish.

Materials and Method

Subjects

Thirteen pigeons served as subjects. Subjects were housed individually in a colony room maintained at 20°C with a 12-hr light/dark cycle. Body weight was maintained at 80% to 85% of free-feeding weight, and water and grits were provided ad lib. With respect to body weight, the economy was open such that subjects received additional food outside of their training sessions if they did not receive enough reinforcements to maintain their body weight. Subjects that were fully trained ($n = 5$) were part of a much larger study investigating the impact of hippocampal lesions on serial order behavior, and, consequently, two had their hippocampus removed at the start of the study. It is important to note that, across the 2- to 3-year training period, the hippocampal lesions had no effect on the performance of subjects on the task used in the current study. This finding is consistent with prior work demonstrating that pigeons display no deficits in short-term memory following hippocampal lesions (Colombo, Swain, Harper, & Alsop, 1997). All procedures were reviewed and approved by the University of Otago Animal Ethics Committee (Protocol 51/16).

Apparatus

Subjects were trained in standard operant chambers. At the front of each chamber was a 17-in computer monitor, and positioned in front of the monitor was a Perspex panel with six 60 mm × 60 mm cutouts. Responses were detected with an infrared touch frame. Food was provided via a hopper located on the floor of the chamber. All stimuli were drawn from a library of 360 gray-scale images of objects, places, people, and animals. The stimuli were novel to all subjects, and no items were used in more than one list.

Procedure

Across all the phases of training and testing, subjects in both the full- and limited-training groups received a single daily session of 96 trials. Subjects in both groups were trained 7 days/week. With respect to stimulus presentation, list items could appear at any of six on-screen locations. The configuration of the list items on each trial was drawn randomly from all possible configurations. For a two-, three-, and four-item list there are 30, 120, 360 possible configurations, respectively. To register a response, only a single peck to a list item was required. All analyses were performed with IBM SPSS Statistics 24 (IBM Inc.).

Initial training. The full-training group ($n = 5$) were first trained on five two-item lists (Lists 1 to 5) using the successive-phase method (D'Amato & Colombo, 1988; Scarf & Colombo, 2010b, 2011). Phase 1 consisted of the first item (A) appearing on screen, with subjects reinforced for responding to it. Given that subjects could not make an error on Phase 1, they were simply trained for 30 trials. In Phase 2, Items A and B were presented simultaneously, and subjects were rewarded for responding to them in the order A → B (Table 1). A standard session lasted 96

Table 1
Summary of Training Phases and Testing

Group	List Length	Lists Number	Phase	Items
Full	AB	1–5	1	A
			2	AB
		6–15	—	AB
	ABC	16–25	1	AB
			2	ABC
		26–45	—	ABC
	ABCD	46–47	1	ABC
			2	ABC-D
			3	ABC-D
			4	ABCD
		48–50	1	ABC
			3	ABC-D
			4	ABCD
		51–60	1	ABC
			4	ABCD
	Test		—	ABCD
Limited	ABCD	1	1	A
			2	AB
			3	ABC
	Test		—	ABC
			4	ABCD
	Test		—	ABCD

trials or until subjects met the rolling block criterion of 24 out of the last 30 trials (80%) correct. Following this, subjects were trained to the same criterion on an additional 10 two-item lists (Lists 6 to 15) in which both items were presented from the start of training.

The subjects were next trained on 10 three-item lists (Lists 16 to 25) using the successive-phase method. Phase 1 consisted of Items A and B being presented simultaneously, and subjects were rewarded for responding to them in the order A → B. In Phase 2, Items A, B, and C were presented simultaneously, and subjects were rewarded for responding to them in the order A → B → C (Table 1). Subjects were trained to a criterion of 24/30 (80%) for Phase 1 and 21/30 (70%) for Phase 2. After acquiring these lists, subjects were trained on an additional 20 three-item lists (Lists 26–45) in which all three items were presented from the start of training.

In the final phase of training, subjects acquired 15 four-item lists (Lists 46–60). Although all 15 lists were trained using the successive-phase method, Lists 46 to 50 included four shaping phases. Specifically, Phase 1 (Lists 46–47) consisted of Items A, B, and C being presented simultaneously, and subjects were rewarded for responding to them in the order A → B → C. In Phase 2, subjects were again presented with only Items A, B, and C; however, after responding to them in the order A → B → C, all three items disappeared, and item D appeared alone (Phase 2). Subjects were only rewarded after responding to item D. The next shaping phase was identical to Phase 2 with the exception that, after responding correctly to items A, B, and C, the three items remained on when item D appeared (Phase 3). Following these three shaping phases, Phase 4 consisted of items A, B, C, and D being presented simultaneously, and subjects were rewarded for responding to them in the order A → B → C → D. For the first two four-item lists (Lists 46 and 47), subjects were trained in all shaping phases, and for the next three lists (Lists 48 to 50), Phase 2 was removed (Table 1). Following List 50, the remaining 10 lists (Lists 51 to 60) simply consisted of Phases 1 and 4. Subjects were trained to a criterion of 21/30 (70%) for Phase 1 and 14/30 (47%) for Phase 1a, Phase 1b, and Phase 2.

The limited-training group ($n = 8$) underwent much less extensive training. Specifically, subjects were trained on a single four-item list using the successive-phase method. Phase 1 consisted of the first item (A) appearing on screen, with subjects reinforced for responding to it. In Phase 2, Items A and B were presented simultaneously, and subjects were rewarded for responding to them in the order A → B. In Phase 3, Items A, B, and C were presented simultaneously, and subjects were rewarded for responding to them in the order A → B → C. In Phase 4, Items A, B, C, and D were presented simultaneously, and subjects were rewarded for responding to them in the order A → B → C → D (Table 1). If the subjects failed to transfer between phases, they were returned to an earlier training phase to reacquire the criterion. Specifically, in transferring from Phase 2 (A → B) to Phase 3 (A → B → C), if a subject completed fewer than 50 trials in a session on Phase 3, they were transferred back to Phase 2 and had to reacquire the criterion. Following reacquisition, the subject was again transferred to Phase 3. Only one subject (B5) failed to immediately transfer between Phase 2 and Phase 3. In transferring from Phase 3 (A → B → C) to Phase 4 (A → B → C → D), if a subject failed to complete three successive sessions on Phase 4, they were transferred back to Phase 3 and had to reacquire the criterion. Given the difficulty of Phase 4, we also used a contingency plan in which, if transferring a subject back to Phase 3 continually failed, we used the additional four-item shaping phases the full-training group received. Only two subjects (B5 and B9) required the additional four-item shaping phases. The criterion for each phase was identical to that of the full-training group (i.e., A: 30 trials; A → B: 24/30; A → B → C: 21/30; A → B → C → D: 14/30).

Testing. Following all phases of their respective training regimes, subjects were presented with a novel four-item list in which all four items were present from the start of training. That is, unlike the four-item training lists that were preceded by various training phases (e.g., A → B → C training), the four-item test was the first time subjects had been presented with a four-item list in absence of any training phases. On a four-item list, the odds of getting the sequence correct with random responding is just 0.9%. Subjects were tested until they either (a) attained the criterion of 20 out of 96 trials correct (21%) or (b) failed to complete an experimental session for three consecutive sessions. Failure to complete a session was operationalized as a subject failing to make a response for 60 min. Once this 60-min time limit was reached, subjects were removed from the operant chamber and returned to their home cage. In addition, to assess whether subjects that received limited training were capable of learning a somewhat easier list, they were also tested with a novel three-item list following Phase 3 of training (Table 1).

Results

All subjects completed all phases of training. With respect to the three-item test list, six of the eight (75%) subjects in the limited-training group achieved criterion, a proportion not significantly different from that of fully trained subjects acquiring their first three-item list in which all items were presented from the start of

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training (six of eight [75%] vs. five of five [100%], $p = .487$, Fisher's exact test). Although a comparable number of subjects in each group acquired the three-item list, fully trained subjects did so in significantly fewer trials than the six successful subjects in the limited-training group (Limited: $M = 1629.167$, $SD = 357.490$ vs. Full: $M = 933.200$, $SD = 390.143$; $t(9) = 3.087$, $p = .013$, Cohen's $d = 1.87$, 95% confidence interval [CI] [0.323, 3.093]).

With respect to the four-item test list, there was a significant difference between the groups. Only one of the eight subjects (12.5%) in the limited-training group learned the novel four-item list, the rest giving up on the task (i.e., failing to complete three consecutive test sessions) anywhere from three to seven sessions (Figure 1A). In contrast, all five subjects (100%) in the full-training group learned the novel four-item list, acquiring it in 10 to 27 sessions (Figure 1B). The difference between the groups was significant ($p = .005$, Fisher's exact test).

To assess whether the more extensive training with four-item lists that the full-training group received may have led subjects to develop a learning set (Harlow, 1949), we assessed the performance of each group over the first three sessions of testing on the novel four-item list. We chose the first three sessions because it was the maximum number of sessions for which all subjects had data. Supporting the learning-set hypothesis, a repeated measures analysis of variance, with Session (3: 1, 2, and 3) and Group (2: full or limited) as factors, revealed a significant effect of Group, $F(1, 11) = 20.540$, $p = .001$, $\eta_p^2 = .651$, 95% CI [0.194, 0.799], but no effect of Session, $F(2, 22) = 1.479$, $p = .252$, $\eta_p^2 = .119$, 95% CI [0.000, 0.332], or Session by Group interaction, $F(2, 22) = 3.647$, $p = .063$, $\eta_p^2 = .249$, 95% CI [0.000, 0.464], reflecting the fact that the full-training group outperformed the limited-training group across the first three testing sessions (Figure 2).

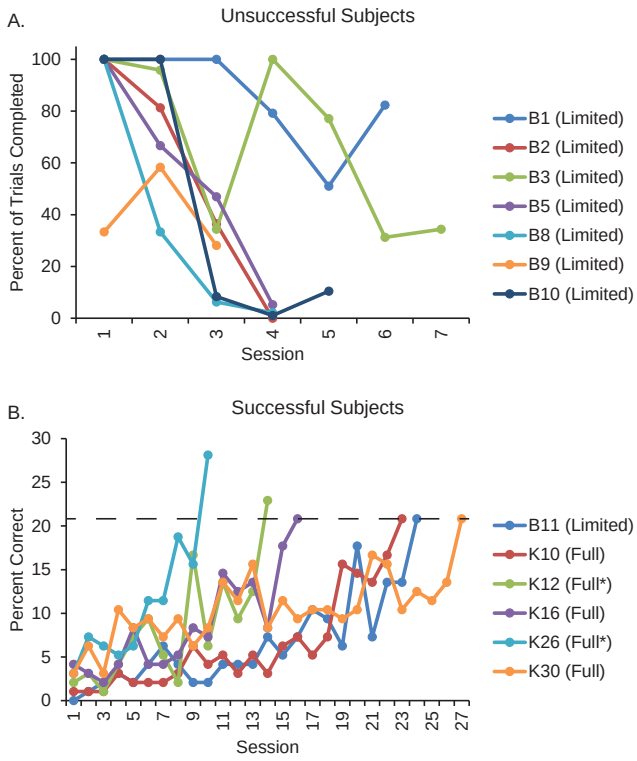


Figure 1. A. The percentage of trials unsuccessful subjects completed on the four-item test list before testing was stopped. Testing was stopped once subjects failed to complete three successive 96-trial sessions. B. The performance of successful subjects over the course of training on the four-item test list. The asterisks indicate the two birds that received hippocampal lesions at the outset of the study. The dashed line indicates the criterion of 20 out of 96 trials correct. See the online article for the color version of this figure.

Discussion

Like monkeys (Swartz et al., 1991, 2000; Terrace et al., 2003), pigeons in the full-training group learnt the order of a four-item list by trial and error, persisting on the task despite receiving few reinforcements over the first few sessions of testing. Further, given a correct trial involves responding to four individual stimuli (i.e., A, B, C, and D), with reinforcement only delivered after responding to the fourth (i.e., D), the rate of reinforcement per response was extremely low. In contrast, with the exception of a single subject, pigeons in the limited-training group quickly gave up on the task. Our finding that the fully trained pigeons completed more correct trials over the first three testing sessions than the pigeons in the limited-training group suggests that over the course of learning the two-item, three-item, and four-item lists and the various shaping phases therein, the fully trained pigeons acquired a learning set (Harlow, 1949; Hodos, 1970). To our knowledge, this finding is one of the few examples of learning-set formation in pigeons. Indeed, to our knowledge, the only previous study to test learning-set formation in pigeons found little evidence that pigeons acquire a learning set when training on a simple S+/S− go/no-go task (Zeigler, 1961).

The present study is not without limitations. First, neophobia may have contributed to the differences between the two groups. Prior to being presented with the novel four-items, subjects in the limited-training group had only been exposed to seven different stimuli. In contrast, the subjects in the full-training group had been exposed to over 150 different stimuli, potentially reducing their neophobia to the novel test stimuli. One could equally argue, however, that the larger number of stimuli the fully trained group were exposed to may have hampered their performance due to the greater potential for interference during the test. Second, we cannot rule out the possibility that the success of subjects in the full-training group was the result of extensive training on lean schedules of reinforcement, rather than the development of a learning set. To answer this question, future studies could test whether pigeons trained on an unrelated task, with an equally lean schedule of reinforcement, are able to learn a novel four-item list.

Emery (2006) noted that the apparent intellectual superiority of primates "may be due to the limited number of species tested in comparative psychology that have neither large relative brain size nor are renowned for their intelligence, such as pigeons" (pp. 23). We would argue that it is equally likely that the apparent intellectual superiority of primates on any given task is due to a contextual variable (Bitterman, 1965; Macphail, 1985). Indeed, as studies on the matching concept (Colombo et al., 2003; Wright, 1997) and serial-order behavior demonstrate (Scarf & Colombo, 2010b, 2011), sometimes comparative psychologists are far too quick to attribute differences in performance to differences in intelligence.

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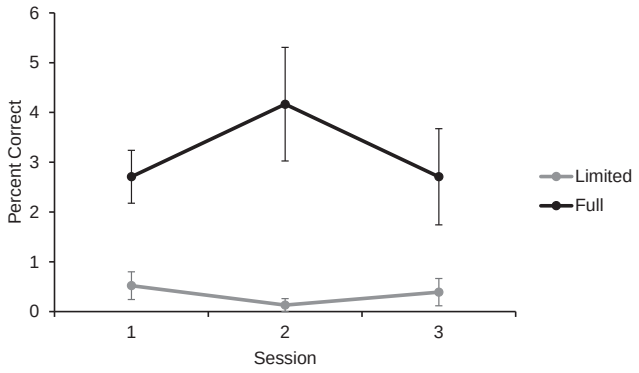


Figure 2. The performance of the limited- and full-training groups over the first three sessions of testing. Error bars represent ±1 standard error of the mean.

In summary, after extensive training, pigeons were able to acquire a four-item list by trial and error, an ability previously only displayed by nonhuman primates (Swartz et al., 2000; Terrace et al., 2003). With the advent of recent computational models of learning on the serial-order task (Enquist, Lind, & Ghirlanda, 2016; Gasser & Arbib, 2017), an intriguing question is whether similar models explain both pigeons' and monkeys' performance. The ultimate question, however, is whether pigeons can learn seven-item lists by trial and error, the longest lists on which monkeys have been trained and for which the chance of success is just 1 in 5,040 trials.

References

Beran, M. J., Pate, J. L., Washburn, D. A., & Rumbaugh, D. M. (2004). Sequential responding and planning in chimpanzees (*Pan troglodytes*) and rhesus macaques (*Macaca mulatta*). *Journal of Experimental Psychology: Animal Behavior Processes, 30,* 203–212. http://dx.doi.org/10.1037/0097-7403.30.3.203

Bitterman, M. E. (1965). The evolution of intelligence. *Scientific American, 212,* 92–100. http://dx.doi.org/10.1038/scientificamerican0165-92

Brannon, E. M., & Terrace, H. S. (1998). Ordering of the numerosities 1 to 9 by monkeys. *Science, 282,* 746–749. http://dx.doi.org/10.1126/science.282.5389.746

Brannon, E. M., & Terrace, H. S. (2002). The evolution and ontogeny of ordinal numerical ability. In M. Bekoff, C. Allen, & G. M. Burghardt (Eds.), *The cognitive animal: Empirical and theoretical perspectives on animal cognition* (pp. 197–204). Cambridge, MA: MIT Press.

Chen, S., Swartz, K. B., & Terrace, H. (1997). Knowledge of the ordinal position of list items in rhesus monkeys. *Psychological Science, 8,* 80–86. http://dx.doi.org/10.1111/j.1467-9280.1997.tb00687.x

Colombo, M., Cottle, A., & Frost, N. (2003). Degree of representation of the matching concept in pigeons (*Columba livia*). *Journal of Comparative Psychology, 117,* 246–256. http://dx.doi.org/10.1037/0735-7036.117.3.246

Colombo, M., Swain, N., Harper, D., & Alsop, B. (1997). The effects of hippocampal and area parahippocampalis lesions in pigeons: I. Delayed matching to sample. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 50,* 149–171.

Cumming, W. W., & Berryman, R. (1961). Some data on matching behavior in the pigeon. *Journal of the Experimental Analysis of Behavior, 4,* 281–284. http://dx.doi.org/10.1901/jeab.1961.4-281

D'Amato, M. (1991). Comparative cognition: Processing of serial order and serial pattern. In L. Dachowsky & C. F. Flaherty (Eds.), *Current topics in animal learning* (pp. 165–185). Mahwah, NJ: Erlbaum.

D'Amato, M. R., & Colombo, M. (1988). Representation of serial order in monkeys (*Cebus apella*). *Journal of Experimental Psychology: Animal Behavior Processes, 14,* 131–139. http://dx.doi.org/10.1037/0097-7403.14.2.131

D'Amato, M. R., Salmon, D. P., & Colombo, M. (1985). Extent and limits of the matching concept in monkeys (*Cebus apella*). *Journal of Experimental Psychology: Animal Behavior Processes, 11,* 35–51. http://dx.doi.org/10.1037/0097-7403.11.1.35

Emery, N. J. (2006). Cognitive ornithology: The evolution of avian intelligence. *Philosophical Transactions of the Royal Society of London Series B, Biological Sciences, 361,* 23–43. http://dx.doi.org/10.1098/rstb.2005.1736

Enquist, M., Lind, J., & Ghirlanda, S. (2016). The power of associative learning and the ontogeny of optimal behaviour. *Royal Society Open Science, 3,* 160734. http://dx.doi.org/10.1098/rsos.160734

Farthing, G. W., & Opuda, M. J. (1974). Transfer of matching-to-sample in pigeons. *Journal of the Experimental Analysis of Behavior, 21,* 199–213. http://dx.doi.org/10.1901/jeab.1974.21-199

Gasser, B., & Arbib, M. A. (2017). A neuro-computational model of sequence learning in macaques: The Simultaneous Chaining Paradigm. *Adaptive Behavior, 25,* 195–213. http://dx.doi.org/10.1177/1059712317715324

Güntürkün, O., Ströckens, F., Scarf, D., & Colombo, M. (2017). Apes, feathered apes, and pigeons: Differences and similarities. *Current Opinion in Behavioral Sciences, 16,* 35–40. http://dx.doi.org/10.1016/j.cobeha.2017.03.003

Harlow, H. F. (1949). The formation of learning sets. *Psychological Review, 56,* 51–65. http://dx.doi.org/10.1037/h0062474

Harris, E. H., Beran, M. J., & Washburn, D. A. (2007). Ordinal-list integration for symbolic, arbitrary, and analog stimuli by rhesus macaques (*Macaca mulatta*). *The Journal of General Psychology, 134,* 183–197. http://dx.doi.org/10.3200/GENP.134.2.183-198

Hodos, W. (1970). Evolutionary interpretation of neural and behavioral studies of living vertebrates. In F. Schmitt (Ed.), *The neurosciences: Second study program* (pp. 26–39). New York, NY: The Rockefeller University Press.

Holmes, P. W. (1979). Transfer of matching performance in pigeons. *Journal of the Experimental Analysis of Behavior, 31,* 103–114. http://dx.doi.org/10.1901/jeab.1979.31-103

Macphail, E. (1985). Vertebrate intelligence: The null hypothesis. *Philosophical Transactions of the Royal Society of London Series B, Biological Sciences, 308,* 37–51. http://dx.doi.org/10.1098/rstb.1985.0008

Scarf, D., & Colombo, M. (2008). Representation of serial order: A comparative analysis of humans, monkeys, and pigeons. *Brain Research Bulletin, 76,* 307–312. http://dx.doi.org/10.1016/j.brainresbull.2008.02.022

Scarf, D., & Colombo, M. (2010a). The formation and execution of sequential plans in pigeons (*Columba livia*). *Behavioural Processes, 83,* 179–182. http://dx.doi.org/10.1016/j.beproc.2009.12.004

Scarf, D., & Colombo, M. (2010b). Representation of serial order in pigeons (*Columba livia*). *Journal of Experimental Psychology: Animal Behavior Processes, 36,* 423–429. http://dx.doi.org/10.1037/a0020926

Scarf, D., & Colombo, M. (2011). Knowledge of the ordinal position of list items in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 37,* 483–487. http://dx.doi.org/10.1037/a0023695

Scarf, D., & Colombo, M. (2018). Serial list learning. In J. Vonk & T. K. Shackelford (Eds.), *Encyclopedia of animal cognition and behavior.* New York, NY: Springer International Publishing. http://dx.doi.org/10.1007/978-3-319-47829-6_1507-1

Scarf, D., Danly, E., Morgan, G., Colombo, M., & Terrace, H. S. (2011). Sequential planning in rhesus monkeys (*Macaca mulatta*). *Animal Cognition, 14,* 317–324. http://dx.doi.org/10.1007/s10071-010-0365-2

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Scarf, D., Hayne, H., & Colombo, M. (2011). Pigeons on par with primates in numerical competence. *Science, 334*, 1664–1664. http://dx.doi.org/10.1126/science.1213357

Scarf, D., Terrace, H. S., & Colombo, M. (2011). Planning abilities of monkeys. In R. M. Williams (Ed.), *Monkeys: Biology, behavior, and disorders* (pp. 137–150). New York, NY: Nova Science Publishers.

Straub, R., & Terrace, H. (1981). Generalization of serial learning in the pigeon. *Animal Learning and Behavior, 9*, 454–468. http://dx.doi.org/10.3758/BF03209775

Swartz, K. B., Chen, S. F., & Terrace, H. S. (1991). Serial learning by rhesus monkeys: I. Acquisition and retention of multiple four-item lists. *Journal of Experimental Psychology: Animal Behavior Processes, 17*, 396–410. http://dx.doi.org/10.1037/0097-7403.17.4.396

Swartz, K. B., Chen, S., & Terrace, H. S. (2000). Serial learning by rhesus monkeys: II. Learning four-item lists by trial and error. *Journal of Experimental Psychology: Animal Behavior Processes, 26*, 274–285. http://dx.doi.org/10.1037/0097-7403.26.3.274

Terrace, H. (1993). The phylogeny and ontogeny of serial memory: List learning by pigeons and monkeys. *Psychological Science, 4*, 162–169. http://dx.doi.org/10.1111/j.1467-9280.1993.tb00481.x

Terrace, H. S., Chen, S., & Newman, A. B. (1995). Serial learning with a wild card by pigeons (*Columba livia*): Effect of list length. *Journal of Comparative Psychology, 109*, 162–172. http://dx.doi.org/10.1037/0735-7036.109.2.162

Terrace, H. S., Son, L. K., & Brannon, E. M. (2003). Serial expertise of rhesus macaques. *Psychological Science, 14*, 66–73. http://dx.doi.org/10.1111/1467-9280.01420

Wright, A. A. (1997). Concept learning and learning strategies. *Psychological Science, 8*, 119–123. http://dx.doi.org/10.1111/j.1467-9280.1997.tb00693.x

Zeigler, H. P. (1961). Learning-set formation in pigeons. *Journal of Comparative and Physiological Psychology, 54*, 252–254. http://dx.doi.org/10.1037/h0041047

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Correction to Robinson et al. (2016)

In the article "Divergent Personality Structures of Brown (*Sapajus apella*) and White-Faced Capuchins (*Cebus capucinus*)" by Lauren M. Robinson, F. Blake Morton, Marieke C. Gartner, Jane Widness, Annika Paukner, Jennifer L. Essler, Sarah F. Brosnan, and Alexander Weiss (*Journal of Comparative Psychology*, 2016, Vol. 130, No. 4, pp. 305–312. http://dx.doi.org/10.1037/com0000037), there was an error in several of the Tables in the Results. The coefficients related to Attentiveness in Tables 5, 6, and 7 were unintentionally reversed-scored. As these associations were not significant, this error had no effect on the interpretation of the results.

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