



**Numerosity Discrimination in the Pigeon
(Columba livia)**

Nicole Félix

UMinho | 2019

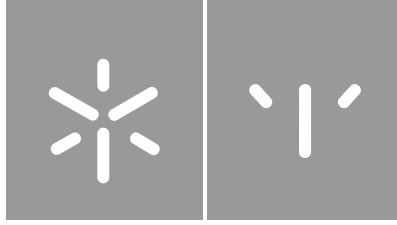


Universidade do Minho
Escola de Psicologia

Nicole Sobral Félix

**Numerosity Discrimination in the Pigeon
(Columba livia)**

outubro de 2019



Universidade do Minho
Escola de Psicologia

Nicole Sobral Félix

**Numerosity Discrimination in the Pigeon
(Columba livia)**

Dissertação de Mestrado
Mestrado Integrado em Psicologia

Trabalho efetuado sob a orientação do
Professor Doutor Armando Machado

e do
Doutor Carlos Pinto

DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS

Este é um trabalho académico que pode ser utilizado por terceiros desde que respeitadas as regras e boas práticas internacionalmente aceites, no que concerne aos direitos de autor e direitos conexos.

Assim, o presente trabalho pode ser utilizado nos termos previstos na licença abaixo indicada.

Caso o utilizador necessite de permissão para poder fazer um uso do trabalho em condições não previstas no licenciamento indicado, deverá contactar o autor, através do RepositóriUM da Universidade do Minho.

Licença concedida aos utilizadores deste trabalho



Atribuição CC BY

<https://creativecommons.org/licenses/by/4.0/>

Acknowledgements

Não só agradeço, como dedico este trabalho aos meus pais. Amor de filha é incondicional, irrestrito e absoluto, mas o meu por vocês é infinito. “A educação dá-se pelo exemplo” e não há orgulho maior que eu tenha na vida do que ser vossa filha. Vocês são o meu mundo.

Aos meus avós, que mesmo sem se aperceberam, facilitaram muito o meu percurso. Ver o olhar orgulhoso e genuíno com o qual olham para mim dá-me das maiores satisfações da minha vida e força para continuar a ultrapassar os obstáculos que possam surgir.

Aos especiais, que desde que chegaram nunca mais saíram: Inês, Sofia, Rita, Joana, Patrícia, Maria, Matilde e Rui. O quanto crescemos juntos! Talvez não o diga tantas vezes quanto gostaria, mas adoro-vos do fundo do meu coração. Obrigada por estarem presentes durante todos estes anos. Outros tantos venham.

Aos melhores que a universidade me deu:

Tania, muito mais que madrinha, foste a minha maior companhia! Nunca a distância vai mudar a nossa amizade. Olho para ti como uma mana mais velha. As saudades que eu tenho de ti.

Vasco, que caminhada! Altos, baixos, muito altos e muito baixos, tudo se passou durante este percurso. *Brother from another mother*. As memórias que temos juntos são agridoces porque foram as melhores e porque acho que nunca serão substituíveis. Como tu, meu amigo.

Mariana, será possível alguma vez me dar tão bem com alguém como contigo? Foste a melhor prendinha que tive durante o curso. Obrigada.

Elsinha, minha Elsinha! É bom saber que há pessoas tão boas, como tu, no mundo. Adoro-te.

Quase finalmente, obrigada ao professor Armando. Que privilégio foi poder ter um orientador com tanto dom para a ciência, com tanta cultura e com tanta ética. Ser fiel a nós mesmos é sem dúvida uma característica rara. E que fonte de inspiração. *If I have seen further than others, it is by standing upon the shoulders of giants*. Obrigada também aos meus colegas de laboratório que me ajudaram e dedicaram um pouco do seu tempo para me ensinar: Renata, Marília, Catarina, Cristina, Alex e Mehdi. Especialmente, ao Carlos, pela imensa ajuda essencial, no decorrer deste ano e meio, na construção deste trabalho. Sem ele não teria sido possível finalizar esta etapa. E claro, ao Miguel, o meu compadre de tese.

Ainda, àqueles que não referi, mas que me apoiaram neste percurso, estou grata.

À Lana, Luna e Nina; são a minha perdição. À Nono, o meu amorzão pequenino.

Por fim, o mais importante:

Duarte, palavras nunca serão suficientes para te dizer o que significas para mim.

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration. I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Braga, October 17th, 2019

Nicole Sobed Felix

Discriminação de Numerosidade em Pombos (*Columba livia*)

Resumo

Animais não-humanos são capazes de discriminar a numerosidade de estímulos e respostas (e.g., Fernandes e Church, 1982; Davis e Albert, 1986; Mechner, 1950). Contudo, a maioria das demonstrações desta capacidade baseou-se numa dicotomia de muita *vs.* pouco. Em outros casos, outras variáveis que se confundem com a numerosidade, como, por exemplo, a duração do estímulo, não foram controladas. De modo a tentar compreender melhor como é que os animais processam numerosidade, seis pombos foram treinados usando uma tarefa de “correspondência-simbólica-para-amostra sem atraso” na qual flashes de luz foram usados como amostra. Primeiro, em cada sessão, os pássaros foram treinados para discriminar duas numerosidades: 2 *vs.* 4 flashes em algumas sessões e 4 *vs.* 8 flashes noutras. Depois, foram expostos a três fases de teste em que as três numerosidades se apresentaram em todas as sessões. Os resultados mostraram que os sujeitos aprenderam a discriminar entre as três numerosidades. Contudo, quando a duração dos estímulos foi manipulada, a performance dos pombos foi afetada negativamente. Uma possível explicação é a dificuldade em isolar as diferentes características do estímulo, neste caso, o número de flashes e a sua duração.

Palavras-chave: sentido de número, numerosidade, percepção temporal, correspondência-para-amostra, pombos.

Numerosity Discrimination in the Pigeon (*Columba livia*)

Abstract

Nonhuman animals have shown to be able to discriminate the numerosity of a stimulus (e.g., Fernandes & Church, 1982; Davis & Albert, 1986). However, most of these demonstrations are based in a few vs. many dichotomy of quantity. Other have been confounded with numerosity, like the stimulus' duration. To understand better how animals process numerosity, six pigeons were trained and tested under a symbolic zero-delay matching-to-sample task (MTS), using light flashes as sample and three response keys as comparisons. First, the birds learned to discriminate two different numerosities in sessions with 2 and 4 flashes and sessions with 4 and 8 flashes. Then, the pigeons were tested, throughout 3 phases, to discriminate the three numerosities in sessions comprising 2 flashes, 4 flashes and 8 flashes. Results showed that pigeons can learn to discriminate three different numerosities. However, when the stimulus durations were manipulated, pigeons' performance was affected negatively. One possible reason is the fact that it is difficult to isolate two characteristics of the stimuli, in this case, numerosity and perception of duration. Further studies could focus on trying to conduct a similar experiment with animals as subjects but using a simultaneous approach instead of a continuous one.

Keywords: number sense, numerosity, timing, matching-to-sample, pigeons.

TABLE OF CONTENTS

INTRODUCTION 9

METHOD.....12

SUBJECTS12

APPARATUS.....13

PROCEDURE.....13

Phase 1.14

Phase 2.14

Phase 3.15

DATA ANALYSIS15

RESULTS.....15

PHASE 116

PHASE 217

PHASE 319

DISCUSSION21

REFERENCES..... 23

TABLES

Table 1. Cumulative durations for each type of sample in each testing phase. 15

Table 2. Average proportion of choices for each sample in phase 3 trials with IFI-1.75s. 20

Table 3. Average proportion of choices for each sample in phase 3 trials with IFI-0.5s..... 20

FIGURES

Figure 2. Individual pigeon data showing the proportion of right choices for every sample numerosity in the last 3 sessions of phase 1. The vertical bar shows the 95% confidence interval if P(short) equaled .5 at the geometric mean. In the last graph, group data is shown. The vertical bar represents the standard error of the mean. 17

Figure 3. Individual pigeon data showing the proportion of right choices for every sample numerosity in the last 3 sessions of phase 1. The vertical bar shows the 95% confidence interval if P(short) equaled .5 at the

Numerosity Discrimination

geometric mean. In the last graph group data is also shown and the vertical bars represent the standard deviation of the mean. 18

Figure 4. Average proportion of correct choices for every type of numerosity on the two types of trials (i.e, trials with 0.5s IFI and 1.75s IFI)..... 19

Numerosity Discrimination

Numerosity Discrimination in the Pigeon (*Columba livia*)

Number related abilities in non-humans have been subject of attention among psychologists for more than a century (e.g., Clever Hans, the counting horse, Pfungst, 1911). In fact, such capacities in animals may serve adaptive and surviving purposes. For example, bees increase their efficiency during the search for food by exploring the numeric regularities in the distribution of their food resources (Bar-shi, Keasa, & Shmida, 2011). Also, when in the wild, animals can struggle at collecting enough food for their survival, making crucial for them to maximize their energy consumption whenever they feed and to do so, they must choose the location with the larger amount of food. Thus, the discrimination between two places with different quantities of food is important because it may lead to greater chances of survival (Emmerton, 2001). Similarly, many birds abandon their nest when a given amount of eggs is removed. For instance, if a nest contains four eggs and two of them are removed, the bird usually deserts, but that does not happen if only one egg is removed (Dantzig, 1930).

Earlier reports suggested that animals could have some type of *number sense*, that is, the capacity to understand if something has changed in a small group of elements (i.e., if something was added or removed), practically spontaneously (Dantzig, 1930). Davis and Memmott (1982) also agree that animals might have some type of *numerical competence*, that is, the ability of an entity to make general comparative magnitude judgements (e.g., few *versus* many apples in a bowl). This notion goes by other names, such as numerical or number discrimination, but the idea under this line of thought is very similar among them. Furthermore, different authors (Davis & Memmott, 1982; Dantzig, 1930; Honig & Stewart, 1989; Davis & Pérusse, 1988) agreed that the concept of numerical competence is different from that of *counting*. Counting is defined as a process to specify the absolute number of items in a given set (e.g., four apples in a bowl) and involves the capacity of transferring such specifications across modalities and procedures (Davis & Pérusse, 1988). On the other side, a relative numerosity discrimination is a judgment of dissimilarity based on magnitude differences (Davis & Pérusse, 1988), a basic ability that does not imply any logical relation to number related abilities (Davis, et al., 1985).

Since nonhumans do not have the same cognitive or behavior abilities as humans (e.g., spoken language), it is not possible to ask an animal how many of elements there are in a group (i.e., cardinality) or its order (i.e., ordinality). There are conditions under which a numerosity discrimination is possible, even without knowing if there are systems of thought that comprise number (Nelson & Bartley, 1961). However, it is not necessary to possess such abilities to make numerosity based judgements (Gelman & Gallistel,

Numerosity Discrimination

1978). Other perceptive or mental processes can be employed to perform such discriminations, such as arbitrary labels that a subject assign to a given numerosity, and not the usual verbal labels (e.g., decimal number system). This is supported by the fact that abstract mental processes involved in mathematical procedures are intrinsic to psychological faculties, because, otherwise, it would not be possible to perform simple discriminations that are the basis for complex mathematical procedures. Therefore, there are natural and primitive classes of numbers, that allow a *number-based discrimination*, and this classes have a *numerosity* (Nelson & Bartley, 1961).

Because of the numerous terminologies used to express the same idea, henceforward, the term *numerosity discrimination* will be used to refer to the capacity of an animal to perform numerosity based judgements, regardless of the nature and complexity of such faculty or the way it is behaviorally exhibited. In experiments that aim to study numerosity in animals, either the quantity of external events (e.g. noises, lights) or animal's own responses can be used as the discriminative stimulus. In a pioneering way, Mechner (1958) developed the fixed consecutive number (FCN) procedure, a refined technique to examine counting behavior in animals, using sequential delivered items and animals' responses as stimuli. Rats had to press lever A at least n times, either 4, 8, 12 or 16 lever presses, and then press a lever B in order to be reinforced. If subjects did not reach the minimum criteria of presses in lever A, n , but pressed lever B, the count had to be repeated. This procedure requires a specific response (in lever B) to signal that the number requirement was met (on lever A), which contrasts with a fixed-ratio (FR) schedule, where a reinforcer is obtained after a specific number of responses.

Although results from Mechner's (1958) experiment revealed that the run lengths on lever A (that is, the number of times the rat presses lever A) were closer to the FR requirement, it is also shown that as n increases, the variability of performance also increases. However, it cannot be assumed that animals were discriminating the number of lever presses. Since there was only a minimum requirement of lever presses, if the animal presses the lever A at a steady rate (like they do in most FR schedules), the number of lever presses can be confounded with the elapsed time since the first press on lever A until moving on to lever B. If this is the case, animals would be timing instead of discriminating numerosity.

As previously referred, to study numerosity discrimination, external events can also be used as stimulus. These events can either be employed simultaneously or sequentially. In the simultaneous approach, visual stimuli are presented at the same time (e.g., Emmerton, Lohmann, & Niemann, 1997; Honig, Karen, & Stewart, 1989). One problem with this type of presentation is that there are variables that

Numerosity Discrimination

can be confounded with numerosity, such as the summed area of the items and the space between them. For instance, imagine that you have two apples in a container and four apples in another equal container, and you have to make a judgement about which container has more apples. However, even though when asked, we tend to say that the judgement was based on number (Emmerton & Renner, 2006). But the summed visual area that we perceive in the container with four apples is bigger than the one with two apples. So, choice could be based on visual area. Therefore, doubts can arise on what was the primary factor that influenced the judgement.

On the other hand, stimuli can also be presented sequentially, like bursts of sound or even flashes of light (e.g., Fernandes & Church, 1982; Davis & Albert, 1986; Davis & Albert, 1987; Catania & Reynolds, 1962). A problem that arises from this approach is the difficulty to isolate numerosity from time. For example, consider an experiment in which an animal is exposed to 1-sec noise bursts. If in a given trial there are 2 bursts separated by an 1-sec mute interval, the sequence of 2 bursts always lasts a total of 3 secs. Likewise, when 4 bursts separated by three intervals of 1-sec are presented, the sequence lasts 7 secs. So, the discriminative stimulus is supposed to be the quantity of bursts, but the animal can also use the overall sequence duration or even the duration of each burst as the discriminative stimulus.

To decorrelate time from numerosity, Fernandes and Church (1982) used a matching-to-sample (MTS) procedure to examine if rats could discriminate between two and four bursts of noise that resulted in a relative number discrimination. After two bursts, the rats had to press the right lever and after four burst the left lever, in order to be reinforced. To assure that discrimination was due to the quantitative features of the stimuli (instead of duration), the duration of each stimulus (i.e., burst of noise) and intersound interval (ISI, i.e., the duration between every burst of the sequence) varied, so that some trials with sequences of two bursts lasted the same of some trials with sequences of four burst. This way, there were not sufficient timing cues for performance. They concluded that rats can successfully discriminate number even when temporal cues are controlled, because they showed a preference for the right lever to be reinforced. However, this bisection task results in a dichotomous judgement, because animals may have learnt to respond based on "few" (two) or "many" (four) sounds, resulting in a relative number discrimination.

Employing a variant of Fernandes and Church (1982) procedure, Davis and Albert (1986) were one of the first to test whether animals were capable of absolute numerical discrimination (Roberts, 1998). In their study three rats were trained under a fixed interval (FI) 1-min schedule. In a FI schedule, the first response given after a fixed amount of time has elapsed is reinforced. Each FI cycle began with the

Numerosity Discrimination

illumination of the houselight and the start of an auditory sequence. The auditory sequence was composed by repetitions of two, three or four bursts of white noise, separated by 4-s intervals (ISI), inside the same trial. Lever presses were only reinforced following FI cycles during which a repeated sequence of three sounds was presented (the probability of a reinforced and no-reinforced trial was the same). Bursts' duration and ISI varied in length. The intertrial interval (ITI) was 10 secs, during which the houselight was turned off and no auditory signals were presented. All subjects showed significantly higher response rates during the "3" stimulus, leading the authors to conclude that subjects were able to discriminate number not only in relative terms (few vs. many), but also in more sophisticated ways by discriminating an intermediate number. Furthermore, one subject showed no significant difference in the discrimination of "3" and "4" stimuli. This finding can be explained by Weber's Law, because the perceptual increase from the stimulus "2" to "3" is bigger (50%), comparing to the "3" to "4" increase (33%). To address this issue, stimuli could have a 2:1 ratio (e.g., sequences of "2", "4" and "8" stimulus), because as the number of bursts in the sequence increases, more difficult is the discrimination. However, as authors themselves note, having a third number to discriminate does not inevitably make the animals express counting or other cognitive process on the basis of absolute number, but certainly provides an ampler view of numerical abilities in animals. Maybe, the level of processing required for an intermediate number task is higher when compared to a many vs few dichotomy (Davis & Albert, 1986). In Davis and Albert (1986) procedure, the reinforcer (food) is only delivered when responses are made following a specific numerosity ("3"). This numerosity is between other two, meaning that the animal is expected to make an intermediate discrimination, probably requiring a level of processing and capacity higher than relative number procedures.

This behavioral study aims to find evidence that birds, particularly pigeons, can discriminate three different numerosities and if their discrimination is based in number, time of both.

Method

Subjects

Six adult pigeons (*Columba livia*) participated in this study. The pigeons were housed in individual cages with free access to water and grit, in a room with a 13:11-hr light/dark cycle (with lights on at 08:00) and controlled temperature (between 20° and 22° C). The animals were maintained at approximately 85% of their free-feeding body weight, fed with mixed grain. Each bird had previously experience with timing procedures (e.g., Pinto & Machado, 2017) and three with choice procedures. The experiment was conducted regularly, approximately at the same time on each day.

Apparatus

Four operant boxes were used. Three of them were Lehigh Valley (LVE) chambers (34 cm high, 35 cm long, 31 cm wide). The response panel had three circular response keys (2.5 cm diameter) arranged horizontally 9 cm apart (center to center) and 22.5 cm above the wire mesh floor. Behind each key was a 12-stimulus Industrial Electronics Engineers (IEE) in-line projector. The food hopper opening (6 cm wide, 5 cm high) was centered horizontally on the response panel, 8.5 cm above the floor. When the hopper was upraised, a 28-V, 0.04-A light illuminated the opening. On the wall opposite the response panel, 30 cm above the floor, a 28-V, 0.1-A houselight provided general illumination and the operant chamber was enclosed in an outer box with an exhaust fan to mask possible outside noises in the experimental room.

The other box was homemade (31 cm high, 33 cm long, 33 cm wide). The response panel had three circular response keys (2.5 cm diameter) arranged horizontally 9 cm apart (center to center), 21 cm above the wire mesh floor. Behind each key was a 12-stimulus IEE projector. A LVE food hooper (6 cm wide, 4.5 cm high) was centered horizontally on the response panel, 6.5 cm above the floor. When activated, a 28-V, 0.04-A light illuminated its opening. The houselight (28-V, 0.1-A) was on the wall opposite the response panel, 27.5 cm above the floor. The operant chamber was enclosed by a PVC sound attenuating cubicle (Med Associates, ENV-018V) equipped with an exhaust fan.

Animal Behavior Environment Test – II (ABET II) software controlled the experimental events and recorded the data.

Procedure

There was no pretraining because all the birds had previous experience with operant procedures. Therefore, they started to peck immediately when the experiment began. A symbolic zero-delay matching-to-sample task with three samples, varying in numerosity, and three comparisons, response keys with white light, was employed. The samples were sequences of 0.5-s houselight flashes and could be composed by 2, 4 or 8 flashes; each flash was separated by a 0.5-s period of darkness during which the houselight was off (i.e., interflash interval, IFI). A sequence always started with a flash and ended with an IFI, so the 2-samples lasted for 2 s, 4-sample lasted for 4 s and 8-sample lasted for 8 s. Numerosity was mapped spatially: for all subjects, the correct comparison for the 2-sample was the left key, for the 4-sample was the center key and for the 8-sample was the right key.

Training

First, the birds were trained to discriminate between two samples, for example, the 2 and 4 (Condition A). All trials started with the sample presentation; immediately after, the two possible comparison keys were illuminated (left and center key), always with white light. After a response, the key lights turned off. When choosing the right comparison by pecking on one of the keys, the birds were always rewarded with 3-secs access to food. The inter-trial interval (ITI) followed, varying from 15 s to 25 s, with all the lights in the box off. After an incorrect choice, ITI followed immediately and the correction method was employed (i.e., the trial was repeated), until the bird gave the right answer. All sessions comprised 60 trials (30 for each numerosity), excluding correction trials. The type of sample was presented in a pseudo-random order (with the constraint that each sample type was presented the same number of times).

When pigeons reached a minimum criterion of 70% correct answers for each sample, for two sessions in a row, they had to discriminate between the 4 and 8-samples (i.e., they changed to Condition B), under the same conditions as in Condition A. Two pigeons started with Condition A and four with condition B. There was no condition with only the extreme numerosities (i.e., 2-sample and 8-sample) because of the importance of the intermediate one. After reaching the same criterion in the second condition, the birds moved to testing.

Testing

Phase 1. All sessions included the three samples. A trial began with either the 2-sample, 4-sample or 8-sample presentation. Then, the three comparisons appeared (i.e., the three keys turned on white). Correct choices were rewarded then the ITI followed. Incorrect choices were followed by the ITI immediately and the correction method employed. Like in the training, both flashes and ITI's lasted 0.5 s. A session had 60 trials, 20 of each type of sample. Once the pigeons reached the minimum criterion of 70% correct choices, for three sessions in a row, they moved to Phase 2.

Phase 2. This phase was similar to the previous, except that the flashes' duration was always 0.25 s. Therefore, a presentation of the 2-sample lasted 1.5 s, the 4-sample lasted 3 s and the 8-sample lasted 6 s. This was a transitional phase, because the pigeons were exposed only to a new duration of the flashes only, before any other future changes in the sample. On the other hand, this was a first step uncorrelating duration from numerosity, since the overall duration of the samples decreased. When the birds reached the minimum criterion of 70% in each sample, for three sessions in a row, they moved to phase 3.

Numerosity Discrimination

Phase 3. All flashes lasted 0.25 s in every sample, but the IFI's duration varied. There were 30 trials in which the sample was composed by 0.5 s IFI's and 30 trials with 1.75 s IFI's (10 for each numerosity). The different durations of the IFI appeared pseudo-randomly throughout the session (with the constrain that each duration appeared the same number of times). This means that every type of sample could have IFI's with 0.5 s and 1.75 s. So, there could be some 2-samples in phase 3 that lasted the same as the 4-sample in phase 1; and there could be some 4-samples in phase 3 that lasted the same as the 8-sample in phase 1 there. This was the final step to decorrelate some numerosities from its sample cumulative duration. Durations of each sample for each phase are presented in table 1.

Table 1.

Cumulative durations for each type of sample in each testing phase.

	Flash	IFI	Sample Numerosity		
			2	4	8
Phase 1	0.5s	0.5s	2s	4s	8s
Phase 2	0.25s	0.5s	1.5s	3s	6s
Phase 3					
<i>IFI 0.5s</i>	0.25s	0.5s	1.5s	3s	6s
<i>IFI 1.75s</i>	0.25s	1.75s	4s	8s	16s

Data Analysis

Statistical and visual analyses were conducted using Microsoft Excel™. The most used statistical test was the single-factor ANOVA, employing a significant level of .05. We reported results for 5 subjects, since one of the pigeons took too long during the pretraining phase and never reached the minimum criterion.

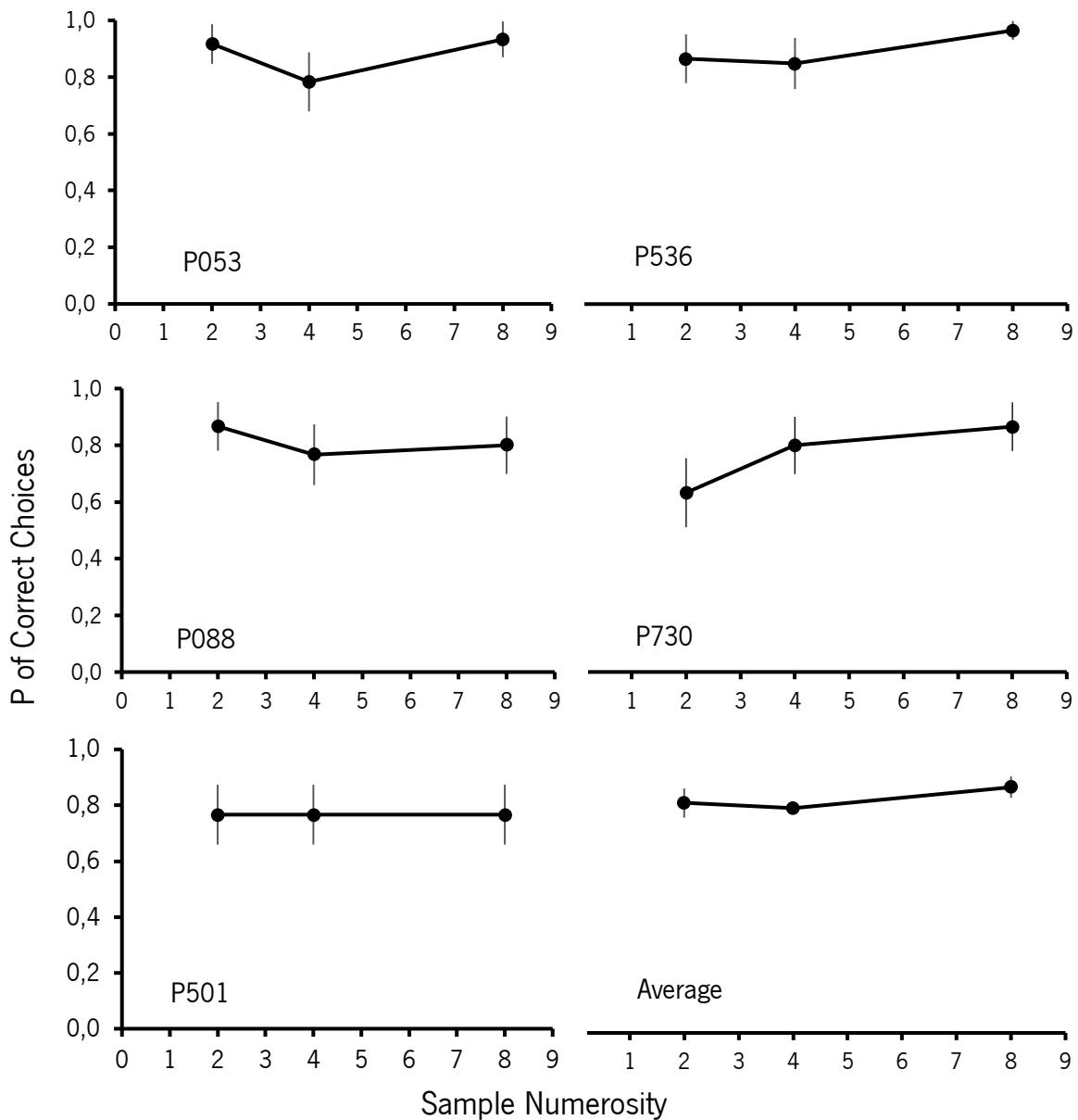
Results

The birds took between 11 and 28 sessions to proceed to the phase 1 of testing (average \approx 21). All birds met the criterion to proceed onto the test. Individual pigeon data is shown for each testing phase.

Numerosity Discrimination

Phase 1

Figure 1 shows the mean proportion of correct choices for each pigeon, regarding the three types of sample, in the last 3 sessions of phase 1. All birds reached the minimum criterion for moving to phase 2, except subject P730 for the sample “2” (mean proportion of correct choices was 67%). However, given that this bird’s performance was consistently above 65%, its data will be considered. Group data is also shown on the last graph.



Numerosity Discrimination

Figure 1. Individual pigeon data showing the proportion of right choices for every sample numerosity in the last 3 sessions of phase 1. The vertical bar shows the 95% confidence interval if $P(\text{short})$ equaled .5 at the geometric mean. In the last graph, group data is shown. The vertical bar represents the standard error of the mean.

As the graphs above suggest, a one-way repeated measures ANOVA yielded non-significant effect of the sample numerosity on pigeons' performance [$F(2,8) = 1.38; p = .31$], confirming that pigeons' performance was equal regarding every type of sample.

Consider the graphs with individual data. The vertical bars represent the 95% confidence interval (CI). This means that the intervals represented have a 95% probability of containing the population mean, if repeated samples were taken. Proportion of correct choices was significantly below chance. Also, proportion of correct choices was visibly stable across subjects.

The bottom right graph of figure 2 shows the mean proportion of right choices of all subjects. The vertical bars represent the standard error of the mean (SEM), that was calculated from the sample distribution. SEM ranged from 0.02 to 0.05; these low values indicate that the mean values of the sample are not very spread.

Concluding, all pigeons showed the same pattern of proportion of correct choices, with no differences regarding the type of sample presented. Group data is consistent with the findings from individual data.

Phase 2

As represented in the previous phase, figure 2 shows the mean proportion of correct choices for each pigeon, regarding the three types of sample, on the last 3 sessions of phase 2.

Numerosity Discrimination

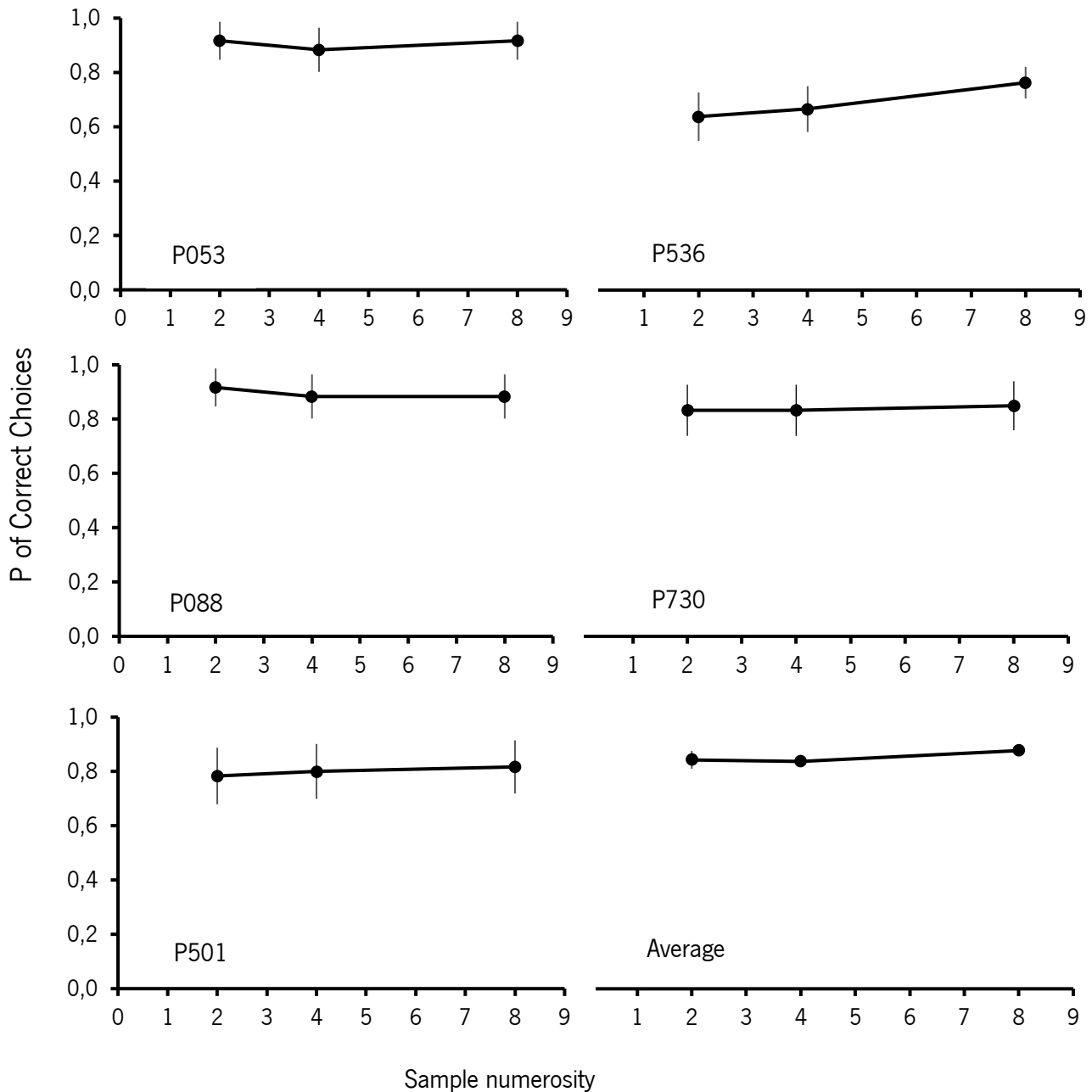


Figure 2. Individual pigeon data showing the proportion of right choices for every sample numerosity in the last 3 sessions of phase 1. The vertical bar shows the 95% confidence interval if $P(\text{short})$ equaled .5 at the geometric mean. In the last graph group data is also shown and the vertical bars represent the standard deviation of the mean.

Individual data shows that the proportion of correct choices was significantly below chance. Considering the overall data (bottom left graph), SEM ranged from 0.02 to 0.03.

Numerosity Discrimination

As in the previous phase, a one-way repeated measures single-factor ANOVA was employed to determine if the birds' performance differed among the three samples and no significant interaction was found [$F(2,8) = 1.67$; $p = .25$], confirming the reading from the graphs.

Results from this phase are similar to the ones found in phase 1. Although the flash duration varied from one phase to the other, pigeons' performance showed no significant difference between them, as t -tests showed no significant differences in the average proportion of correct choices, between the two phases, for sample "2" ($t(4) = -0.66$, $p = 0.27$), for sample "4" ($t(4) = -1.52$, $p = 0.10$) and for sample "8" ($t(4) = -0.42$, $p = 0.35$).

Phase 3

In this phase, pigeons' performance on trials with IFI-0.75s and IFI-0.5s was compared. Figure 4 represents pigeons' performance on the first session of phase 3. The birds' performance was evidently affected by the new types of trial (i.e., trials with 1.75s IFI's).

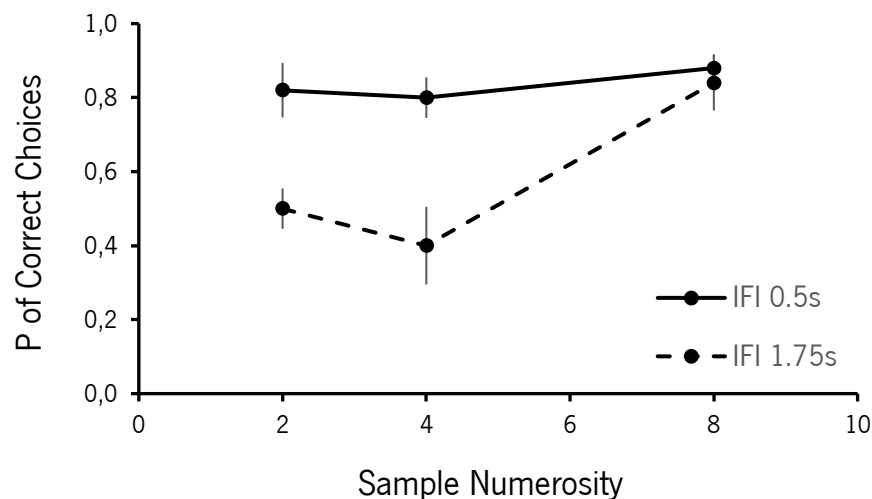


Figure 3. Average proportion of correct choices for every type of numerosity on the two types of trials (i.e., trials with 0.5s IFI and 1.75s IFI).

The reading of the graph (figure 4) is supported by the results from a two-factor mixed ANOVA. There was a significant main effect of the type of trial [i.e., IFI duration; $M(0.5) = 0.83$; $M(1.75) = 0.58$], $F(1,4) = 76$; $p < .001$. Also, there was a significant main effect of numerosity, [$M(2) = .66$, $M(4) = .6$, $M(8) = .86$], $F(2,8) = 6.66$; $p = .02$. However, there was not a significant interaction between the trial type and IFI, $F(2,8) = .08$; $p = .15$.

Numerosity Discrimination

Vertical bars represent the SEM in IFI 0.5s and IFI 1.75s trials (that ranged from 0.04 to 0.07 and from 0.05 to 0.10, respectively).

Additionally, we examined the choices pigeons made in the IFI-1.75s trials. Please recall that in these trials, the 2-samples last the same as 4-samples in phase 1 (4s); as well, 4-samples last the same as 8-samples from phase 1 (8s).

Table 2.

Average proportion of choices for each sample in phase 3 trials with IFI-1.75s.

Choice	Sample numerosity		
	2	4	8
"2"	.5	.1	.02
"4"	.36	.4	.14
"8"	.14	.5	.84
Total	1	1	1

From the reading of table 2, the pigeons show a pattern of choice consistent with the results from the two-factor mixed ANOVA, that the trial type (i.e., duration) affected subjects' performance. When comparing to the IFI-0.5s trials within the same session we could observe that the proportion of choices concerning the 8-sample was the least affected. However, the proportion of choices for the 4-sample dropped 50% (table 2) compared to choices in 0.5s-IFI's (table 3).

It is also possible to observe that the choices represented in table 2 are consistent with the discrimination of time, meaning the birds did learn this discrimination in previous phases. For instance, consider the 2-sample.

Table 3.

Average proportion of choices for each sample in phase 3 trials with IFI-0.5s.

Choice	Sample numerosity		
	2	4	8
"2"	.82		
"4"		.8	
"8"			.88

Discussion

This study investigated whether pigeons could discriminate three different numerosities – 2, 4 and 8 – by employing a matching-to-sample (MTS) procedure. Throughout three phases, we recorded the behavior of the same five pigeons.

Results from phase 1 showed that all pigeons learned to discriminate the three numerosities. Studies show that non-human animals can learn to perform such discriminations; however, these studies used mainly bisection tasks, with only two numerosities (e.g., Tan & Grace, 2010) and it was unclear whether birds could learn to perform more complex discriminations. If so, then pigeons can probably successfully execute experiments that require higher cognitive abilities or, at least, that are more complex than the ones present in the literature so far.

By analyzing pigeons' behavioral patterns (in this case, their keys choices) in Figure 1, we concluded that pigeons are able to learn to discriminate three different numerosities. Furthermore, their performance did not significantly differ among the three types of samples, meaning that the degree of subjective response difficulty was the same for all numerosities. According to the literature, relative number discrimination is a basic ability that allows magnitude estimation (Davis & Pérusse, 1988; Davis & Memmot, 1982), for example, of two vs. four items. If the pigeons can discriminate among three different magnitudes, this implies they are able to learn more complex discriminations than many vs. few. Fernandes and Church (1982) and Davis and Albert (1986), arrived at the same conclusion, using mice as subjects. However, to our knowledge, no similar study so far uses birds (specifically pigeons) as subjects to determine if this species is capable of executing more than just a relative estimation of number with more types of numerosity. We show that pigeons can successfully discriminate among three types of sample with different numerosities, equally.

Phase 2 was an intermediate phase. We started the attempt to separate "time" from "number", changing the duration of the light flashes. Once again, the birds showed no difference in the performance among the three types of sample. Furthermore, the response pattern was as stable as in phase 1.

Numerosity Discrimination

By changing the duration of the flashes, we inherently changed the cumulative duration of the overall samples. Even though this was not a major variation, one can conclude that, if the performance was not significantly altered, then the pigeons are not responding basing their choices merely on timing cues.

In phase 3, however, limitations linked to the difficulty of decorrelating time from number are evident. The main problem with sequential stimulus presentation is that, by analyzing subjects' performance, it is not empirically possible to conclude that the results are due to numerosity discrimination, since that the presentation of the stimuli is always the same when the numerosity is the same as well.

To overcome this limitation, we varied trial duration. Some trials with the 2-sample had the same duration as trials with the 4-sample in phase 1, and approximately as in phase 2. Likewise, some trials with the 4-sample lasted the same as the trials with the 8-sample in phase 1. Therefore, if pigeons were responding to numerosity features of the stimuli, their performance would not be affected by changes in duration. However, results from phase 3 show that the birds' performance was negatively affected. Proportion of right choices dropped in all subjects.

The decrease in the proportion of correct responses in the trials with manipulated duration implies that the pigeon is sensitive to the timing properties of the stimuli. It is very well known that pigeons exhibit behavioral evidence for episodic memory (by recalling events that happen at certain time in the past) and can anticipate events that will happen at a certain moment in the future (Roberts, 2002); that is, they have sense of time. However, they are also sensitive to number-related features of stimuli, because their behavior in the trials with different durations was not based solely on a timing discrimination. If so, the proportion of right choices should have been even more evident on trials with 1.75s-IFIs, because they would have learned to respond to time only (figure 4).

Also, table 2 and table 3 provide some comprehension about how pigeons responses were distributed throughout the testing. In phase 3, during trials with similar durations to the previous phases (i.e., 0.5s-IFI trials), birds' performance was not visibly affected. By the other hand, when duration was prominently manipulated, performance was negatively affected: the choices pattern altered, and proportion of correct choices dropped. Moreover, this decline was equal across subjects.

Also, table 1 shows that when the sample numerosity was 4, pigeons mostly chose the comparison for the 8-sample (right key). Given that during these trials the 4-sample lasted the same as the 8-sample from previous phases, this result is consistent with the interference of time on pigeons' choices. An interesting finding is that the, even though the most of their choices are consistent with a discrimination of

Numerosity Discrimination

timing properties (50%), and the choices consistent with a discrimination of number dropped (from 80% to 40%), these proportions are very similar. It appears that they are responding to both properties of the stimuli, number and time.

A possible explanation for these findings can be that these two stimulus properties (i.e., numerosity and duration) overlap. This means that the pigeon could always be timing and/or counting the same stimuli. Thus, pigeons may be responding to more than one property of the stimuli; they may consider time, number or even both.

Evidence for this idea is reported by Roberts and Mitchell (1994). They admit that pigeons can process temporal and numerical information simultaneously. They studied these two properties of the stimuli to find what they could have in common, because of all the evidence in the literature about temporal and numerical competence in non-human animals. They concluded (from experiment 1) that pigeons were able to learn a discriminated based solely on number cues. Eventhough they manipulated the durations and birds clearly learned the discrimination, they had only two numerosities (2 and 8). Again, this is consistent with a relative number discrimination.

This study reveals a broader knowledge on how birds, especially pigeons (*Columba livia*), perform when presented with three different stimulus' numerosities. We contributed to this field of investigation by manipulating different features of the stimulus (in this case, duration), while maintaining other parameters intact.

Nevertheless, there are still many questions yet to be answered. Is it possible to completely decorrelate time from number? Can pigeons really rely on just number cues to make choices? Further studies should focus on trying to answer these questions, as well as trying different procedures (e.g., simultaneous approach) to do so.

Concluding, performance was affected by timing properties, but from these evidences we concluded that they are also sensitive to numerosity cues of the stimuli.

References

- Bar-Shai, N., Keasar, T., & Shmida, A. (2011). The use of numerical information by bees in foraging tasks. *Behavioral Ecology*, *22*(2), 317-325. <https://doi.org/10.1093/beheco/aru206>.
- Dantzig, T. (2005). *Number: the language of science*, edited by J Mazur. New York: Pi Press.
- Davis, H., & Albert, M. (1986). Numerical discrimination by rats using sequential auditory stimuli. *Animal Learning & Behavior*, *14*(1), 57-59. <https://doi.org/10.3758/BF03200037>.

Numerosity Discrimination

- Davis, H., Albert, M., Barron, R. W., Starkey, P., Gelman, R., & Spelke, E. S. (1985). Detection of number or numerosness by human infants. *Science*, *228*, 1222-1223. DOI: 10.1126/science.228.4704.1222-a.
- Davis, H., & Memmott, J. (1982). Counting behavior in animals: a critical evaluation. *Psychological Bulletin*, *92*, 547-571. <http://dx.doi.org/10.1037/0033-2909.92.3.547>.
- Davis, H., & Pérusse, R. (1988). Numerical competence in animals: Definitional issues, current evidence, and a new research agenda. *Behavioral and Brain Sciences*, *11*(4), 561-579. <https://doi.org/10.1017/S0140525X00053437>
- Emmerton, J. (2001). Birds' judgments of number and quantity. In R. G. Cook (Ed.), *Avian visual cognition*. [On-line]: <http://www.pigeon.psy.tufts.edu/avc/emmerton/>.
- Emmerton, J., Lohmann, A., & Niemann, J. (1997). Pigeons' serial ordering of numerosity with visual arrays. *Animal Learning & Behavior*, *25*(2), 234-244. <https://doi.org/10.3758/BF03199062>.
- Emmerton, J., & Renner, J. C. (2006). Scalar effects in the visual discrimination of numerosity by pigeons. *Learning & Behavior*, *34*(2), 176-192.
- Fernandes, D. M., & Church, R. M. (1982). Discrimination of the number of sequential events by rats. *Animal Learning & Behavior*, *10*(2), 171-176. <https://doi.org/10.3758/BF03212266>.
- Geary, D. C., Hoard, M. K., Byrd-Craven, J., Nugent, L., & Numtee, C. (2007). Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. *Child development*, *78*(4), 1343-1359.
- Honig, W. K., & Stewart, K. E. (1989). Discrimination of relative numerosity by pigeons. *Animal Learning & Behavior*, *17*(2), 134-146. <https://doi.org/10.3758/BF03207628>.
- Mechner, F. (1958). Probability relations within response sequences under ratio reinforcement. *Journal of the Experimental Analysis of Behavior*, *1*, 109-122. <https://doi.org/10.1901/jeab.1958.1-109>.
- Nelson, T. M., & Bartley, S. H. (1961). Numerosity, number, arithmetization, measurement and psychology. *Philosophy of Science*, *28*(2), 178-203. <https://doi.org/10.1086/287799>.
- Pfungst, Oskar. [1911] 1965. *Clever Hans (The Horse of Mr von Osten): A Contribution to Experimental Animal and Human Psychology*. Edited by Robert Rosenthal. New York: Holt, Rinehart & Winston.
- Reynolds, G. S., & Catania, A. C. (1962). Temporal discrimination in pigeons. *Science*, *135*(3500), 314-315. DOI: 10.1126/science.135.3500.314.

Numerosity Discrimination

- Roberts, W. A. (2002). Are animals stuck in time?. *Psychological bulletin*, *128*(3), 473. DOI: 10.1037/0033-2909.128.3.473.
- Roberts, W. A., & Mitchell, S. (1994). Can a pigeon simultaneously process temporal and numerical information?. *Journal of Experimental Psychology: Animal Behavior Processes*, *20*(1), 66. <http://dx.doi.org/10.1037/0097-7403.20.1.66>.
- Tan, L., & Grace, R. C. (2010). Discrimination and representation of relative numerosity in a bisection task by pigeons. *Learning & behavior*, *38*(4), 408-417. doi: 10.3758/LB.38.4.408.