Universidade do Minho

Escola de Psicologia

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Multiple-coding vs Single-code/Default: Analysis of Learning Strategies in Pigeons

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Professor Doutor Carlos André Ribeiro Oliveira Pinto

junho de 2025

DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS

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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.

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Universidade do Minho, 07 de junho de 2025



(Osvaldo Medeiros Roque)

Multiple-coding vs Single-code/Default: Analysis of Learning Strategies in Pigeons

Abstract

To understand what learning strategies pigeons may use, we used a Symbolic Matching-to-Sample task with three temporal samples (2, 6 and 18 seconds) where 2s was associated with one comparison (C1) and 6 and 18s were associated with the other comparison (C2). To learn these associations, animals could use two strategies: multiple-coding or single-code/default. In the former, animals create a code for each sample (e.g., "If 2s, then C1"; "If 6s, then C2"; "If 18s, then C2"). In the latter, they create two codes, one specific to one sample (a single-code) and another that applies to all other samples, as a default rule (e.g., "If 2s, then C1"; "If ≠ 2s, then C2"). In four different tests – a Dark Delay Test, a Generalization Test, a Lit Delay Test, and New Sample-delay Test – pigeons revealed behavioral patterns consistent with the single-code/default hypothesis in tests with delays. The Generalization Test yielded ambiguous results that could be explained by a multiple-coding or single-code/default. Considering these results, we conclude that animals can use the single-code/default as a learning strategy.

Keywords: Coding, Many-to-one mapping, Multiple-coding, Pigeons, Single-code/default.

Multiple-coding vs *Single-code/Default*: Análise de Estratégias de Aprendizagem em Pombos

Resumo

Para compreender quais as estratégias de aprendizagem utilizadas por pombos, construímos uma tarefa de correspondência à amostra simbólica com três amostras temporais (2, 6 e 18 segundos). A amostra de 2s foi associada a uma comparação (C1) e as amostras de 6 e 18s foram associadas à outra comparação (C2). Para aprender esta tarefa, os animais podem usar duas estratégias: *multiple-coding* ou *single-code/default*. Na primeira, os animais criam um código para cada amostra (e.g., "Se 2s, então C1"; "Se 6s, então C2"; "Se 18s, então C2"). Na segunda, criam dois códigos: um específico para uma das amostras (*single-code*) e outro que abrange as restantes amostras como uma regra padrão (*default*) (e.g., "Se 2s, então C1"; "Se ≠ 2s, então C2"). Através de quatro testes – um Teste de *Delay* Escuro, um Teste de Generalização, um Teste de *Delay* Iluminado e um Teste de *New Sample-delay* – os pombos revelaram padrões comportamentais consistentes com a hipótese *single-code/default* nos testes com *delay*. O Teste de Generalização produziu resultados ambíguos que podem ser explicados pela estratégia *single-code/default* ou pela *multiple-coding*. Depois de considerar todos os resultados, concluímos que os pombos conseguem usar a estratégia *single-code/default* como uma forma de aprendizagem.

Palavras-Chave: Codificação, Mapeamento many-to-one, *Multiple-coding*, Pombos, *Single-code/default*.

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Introduction

To interact with the environment, animals may use response rules (or codes) to solve problems and day-to-day situations. In a complex world, with a plethora of situations, the ability to flexibly create codes can be the difference between survival and death, since certain strategies can be better than others. Understanding what strategies animals use is important as it will help us deepen our knowledge of the learning process.

To uncover which strategy animals use, we implemented a Symbolic Matching-to-Sample task for the pigeons to learn. This task starts with a lit white key – also called sample – in the operant chamber, that can be lit for different durations (e.g., 2 or 10s). Once the white key turns off, two other keys – also called comparisons – are instantly turned on with different colors (e.g., red and green), allowing the animal to make a choice by selecting one of them. The task is created in a way that whenever the sample has a duration of 2 seconds and the animal chooses the red comparison, it is rewarded with food, but if the green comparison is selected instead it is not rewarded; conversely, if the sample has a duration of 10 seconds, and the animal chooses the green comparison, it is rewarded with food, but if it chooses the red comparison it is not rewarded. With this procedure, the animal learns to associate the 2-s sample with the red comparison and the 10-s sample with the green comparison.

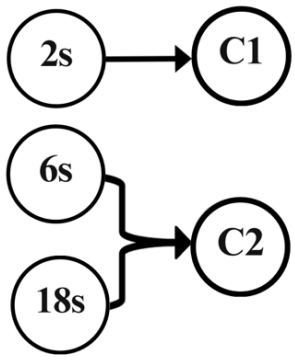
To learn this task, animals may use two strategies: multiple-coding or single-code/default. In multiple-coding strategy, as the name implies, animals create a code for each sample-comparison association; in the foregoing example, the codes would be “If 2s, then red”; “If 10s, then green”. In the single-code/default strategy, animals also create two codes, one for the association it memorizes (the single-code) and another that it uses as a default rule for all the other samples (the default code); in this case the codes would be “If 2s, then red”; “If ≠ 2s, then green”. Although both strategies can solve this task, the single-code/default strategy is arguably more economical as it can be generalized to an undetermined number of samples, with the same two codes (assuming the samples share the same comparison).

Although both strategies can solve this task, the single-code/default strategy becomes advantageous in tasks with many-to-one mappings, where more than one sample is associated with a comparison. For example, imagine a many-to-one mapping with 2, 6 and 18-s samples, where the 2-s sample is associated with a red comparison (C1) and 6 and 18-s samples are associated with a green

comparison (C2) (Fig. 1). If the animals use a multiple-coding strategy they would create a code for each of the samples (e.g., "If 2s, then C1"; "If 6s, then C2"; and "If 18s, then C2"). Though functional, this strategy has obvious drawbacks because pigeons have to remember samples that are associated with same comparison. But in case they use a single-code/default strategy only two codes are needed. One specific to one sample, and the default rule that is applied to all other samples (e.g., "If 2s, then C1"; "If ≠ 2s, then C2").

Figure 1

Representation of a many-to-one mapping used in this experiment



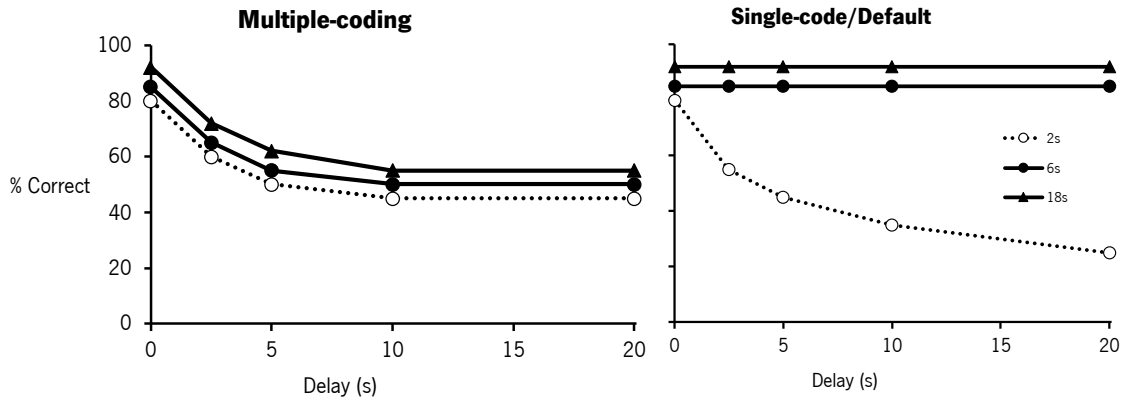
Note. Left circles represent the sample durations (2, 6 and 18s) and right circles represent the comparisons (C1 and C2). Arrows indicate the association.

Regardless of the strategy used in a many-to-one mapping, the overall result would be the same – the task would be learned equally well. For that reason, other studies that investigate similar topics use a Delay Test to discover which strategy is employed. In this test, a delay is implemented between the sample offset and the comparisons onset, causing the sample memory to be forgotten and more errors to be committed as a function of the delay – where longer delays lead to higher proportions of mistakes. The logic being that strategies that use different mnemonic codes should lead to different response patterns. Take the 2-s sample, for example. If animals use a multiple-coding strategy, the percentages of correct responses for this sample should gradually decrease as the delay lengthens, until it reaches 50% of correct responses in longer delays (when the memory is completely lost, the animal responds randomly to both C1 and C2). Given that this strategy creates similar codes for all samples, the 6 and 18-s samples ought to have similar response patterns, which would lead to similar forgetting functions for each one (Fig. 2, left panel). On the other hand, if an animal uses a single-code/default, it should respond based on the presence or absence of the sample with the single-code: when the 2-s sample is presented, it will respond C1 because the sample is equal to 2s; when the 6 or 18-s samples are presented, it will respond

C2 because they are different from 2s. But when the samples are presented with a delay, and the memory of those samples is lost, it will respond C2 because the lack of memory is also "different from 2s". Therefore, the functions associated with the default samples (6 and 18s) would remain high across the delays, whilst the single-code sample (2s) would decrease below indifference levels (i.e., 50% of correct responses), resulting in asymmetrical forgetting functions (Fig. 2, right panel). Additionally, the 6 and 18s functions should be similar because they are both different from 2s.

Figure 2

Theoretical functions representing the use of a Multiple-coding strategy (left panel) and a Single-code/Default strategy (right panel), by percentages of correct responses (y-axis) in varying delays (x-axis) to tree samples (2, 6 and 18s)



Note. The functions were purposely drawn apart in the left panel, and in the 6 and 18-s samples in the right panel, for clarity.

Singer et al. (2006, Experiment 2) used a many-to-one mapping of three temporal samples (2, 8 and 32s) and two comparisons (C1 and C2), where pigeons had to learn to associate the 2 and 32-s samples to C2 and the 8-s sample to C1. When pigeons proceeded to the Delay Test, the percentages of correct responses for the 8-s sample fell below 50%, and the percentages for the 2 and 32-s samples remained similarly high – in other words, in longer delays, pigeons chose C2 independent of sample – a result consistent with the single-code/default. However, in this mapping, the shortest sample was associated with the default option, and pigeons could have been showing a preference for the comparison associated with the shortest duration, a phenomenon commonly found in durations discrimination tests, known as choose-short effect (e.g., Spetch & Wilkie, 1982; 1983). In this perspective, pigeons could have created a code separately for each sample and when the sample information was lost, choose C2 because it is the option associated with the shortest duration. This would lead to similar functions as the ones expected from a single-code/default strategy while being the fruit of multiple-coding.

To discriminate between choose-short effect and single-code/default, Pinto and Machado (2015) used a many-to-one mapping with three temporal samples (2, 6 and 18s). Where the long duration samples (6 and 18s) were associated with C2 and the short sample (2s) was associated with C1. With this mapping, a choose-short effect or single-code/default should lead to different results. If pigeons preferred "short" comparisons on delay tests, they would respond mostly on C1, resulting in asymmetrical functions, where the retention functions for 6 and 18-s samples would decrease, and the 2-s function would remain high. In case they used a single-code/default the pattern should invert as the samples with long durations (6 and 18s) are associated with C2. The Delay Test showed percentages of correct responses for long samples remained high and relatively stable, while the percentages for the short sample dropped to below indifference levels, supporting the use of a single-code/default.

However, pigeons may use several stimuli to learn the task besides the samples' duration. Other protruding stimuli, like the activation of the feeder, sounds, and lights that turn on and off, can be used as markers to discriminate the passage of time. In the previous study, temporal markers like the offset of the ITI ("inter-trial interval" that separates trials) and the onset of the comparisons, could be used to discriminate the duration to be timed, while ignoring the sample itself. This would result in identical estimations of time as the sample durations on the training phase, but on the delay trials, judgments of time would increase as the "stop" marker – the comparisons onset – arrived later with delays. That being the case, pigeons would have a generalized preference for "long" comparisons, and the functions encountered in the previous study could be the result of the adoption of time markers and not a reflection of a single-code/default strategy.

To clarify which time markers animals use, the same authors, in 2017, developed a study to investigate if ITIs influence time estimates. With an identical many-to-one mapping, with three samples (2, 6 and 18s), they separated the pigeons into two groups during training. One where ITIs were illuminated ("Lit-ITI") and another where the ITIs were spent in the dark ("Dark-ITI"). In test trials, they presented no-sample trials (in which comparisons are presented immediately after the ITI) with and without delays. The purpose of the test was to investigate whether pigeons would prefer the "long" comparisons following a delay, as in the previous study, even in the absence of a sample. The rationale being that, if they do, they are using the ITI and comparisons to estimate the passage of time. In the "Lit-ITI" group, in trials without delays, pigeons mostly chose C1, the comparison associated with the short duration. In trials with delays, the choices switched, and pigeons started to select C2, the comparison associated with the long duration. In the "Dark-ITI" group, in identical trials, the animals remained at

indifference levels across the delay. These results indicate that the samples are not the only stimuli used to discriminate the passage of time. The ITI, signaled by the chamber's houselight, and the light of the comparisons, can therefore be used as time markers to learn the task.

The single-code/default strategy has been studied by different authors since the beginning of the century (see: Gaitan & Wixted, 2000; Pinto & Machado, 2015; Pinto & Queiroz, 2024; Singer & Zentall, 2006). The results from these studies suggest that animals are capable of implementing response rules based on one of the stimuli. However, confounds such as the choose-short effect and unwanted temporal markers can simulate the results expected by a single-code/default strategy while stemming from a multiple-coding. To conclusively understand what strategy animals use, it is necessary to create a methodology that controls these confounding variables.

To accomplish this goal, this study uses a many-to-one mapping of three samples (2, 6 and 18s), where the 2-s sample was associated with C1, and the 6 and 18-s samples were associated with C2, avoiding confounds with a choose-short effect. Additionally, we removed the ITI from the procedure, preventing the use of the ITI offset and comparisons onset as time markers. Then, pigeons performed four tests that investigate learning strategies through different lenses. The first test is a Dark Delay Test in which different durations (e.g., 2.5, 5, 10 and 20s) were inserted between the samples offset and comparisons onset.

The second experiment, a Generalization Test, investigates what strategy animals use by presenting new samples and recording how they react. The rationale being, that if animals use the single-code/default and are presented with new sample durations, they ought to respond with the default code because it is different from the 2-s sample. This would result in high percentages of choosing C2 (the comparison associated with the default code) in trials where new samples were presented. However, time exists on a continuum dimension where does not exist a concrete line separating one temporal stimulus from another. Although a 1-s sample is physically different from the 2-s sample, pigeons might perceive it as being one from training, not realizing they are seeing new samples. Similarly, if we presented a 5-s sample, pigeons might confuse it with the 6-s sample learned in training. These possibilities would invalidate the purpose of the test. To avoid that, we used a sample duration that has the least possibility of being perceived as a sample present in training: 3.46-s sample. This sample is the bisection point between 2 and 6s (found by calculating the geometric mean) and it represents the psychological midpoint between 2 and 6s – meaning it is equally different from the 2 and 6-s sample.

On a similar vein, if pigeons use a multiple-coding they could perceive the 3.46-s sample as being more similar to 2s in some trials and more similar to 6s in other trials, given that the 3.46-s sample is equally different from both 2 and 6-s sample. This would lead animals to choose the C2 option in some trials and the C1 option in other trials, leading to values close to 50%. However, this possibility is not a conclusive pattern in favor of a multiple-coding, because it could also arise in case of a single-code/default. In this case, if pigeons do not perceive the 3.46-s sample as different, they might perceive it as being "equal to 2s" in some trials and as being "different from 2s" in other trials, leading to the same 50% values. Therefore, if pigeons respond to the new sample with high percentages of C2, we can conclude that single-code/default is being used, but in case they are indifferent to the new sample, is inconclusive, as it could be explained by both strategies. Additionally, we used no-samples (a 0-s sample where the comparisons are presented immediately after the end of the previous trial), as the second new sample, to investigate what response would elicit. Although there is evidence of generalization in no-sample tests (Pinto & Salgado, 2023) – meaning it is perceived as being part of the temporal continuum – it is also qualitatively different from other samples. So, we were interested in seeing if a "default" response would emerge in no-sample trials.

The third test, the Lit Delay Test, is similar to the Dark Delay Test, with the difference that delays are now lit. Contrary to the previous tests, the Lit Delay Test does not directly investigate which strategy animals employ (multiple-coding vs single-code/default); rather it investigates if the contents of the delay would change the response patterns. Soares et al. (2025) found that following training on a Symbolic Matching-to-Sample task with one-to-one mapping, pigeons showed typical forgetting functions in a darken delay test. But when the delay was lit by the houselight, pigeons showed a preference for the shortest sample duration. This unintuitive result reveals that the duration of the delay is not the only influence on response patterns; what happens during the delay also has an effect. Hence, the Lit Delay Test investigates if changing the contents of the delay test would change the response patterns, compared to the Dark Delay Test.

The fourth test further investigates the learning strategies through responses to new stimulus, but this time by the use of samples that are different in appearance. As showed in the Generalization Test, due to the continuous nature of time, it is difficult to find a sample that would be perceived different from 2s without the possibility of being generalized. For this purpose, we created the New Sample-delay Test in which samples that are different in appearance from the ones learned during training are presented in an attempt to decrease the possibility of generalization. Therefore, the logic behind this test

is similar to the Generalization Test: if pigeons use a single-code/default strategy, samples that are different in appearance should be perceived as different from 2s and elicit a "default" response, leading to high percentages of choosing C2. To accomplish this, we used the bisection point from the Generalization Test (3.46s) to control for temporal similarity and changed the hue color to blue. We also used a 3.46s sample, identical to the Generalization Test, to compare the responses with the 3.46s blue sample. Additionally, trials with delays were added in an exploratory effort to investigate what response patterns would emerge when new samples are combined with delay trials. Thus, the New Sample-Delay Test uses two 3.46-s samples – one marked by a white hue and another by a blue hue – and varying delays, to uncover what response patterns would emerge.

Method

Participants

Eight pigeons (*Columba livia*) were kept at approximately 85% of their free-feeding weight with grit and water freely available. The colony room, was kept on a circadian cycle of 13:11 hours, with the lights on from 8:00 a.m. to 9:00 p.m. with a temperature of 20 °C to 22 °C. The experiments took place once a day, seven days per week, at approximately the same time for each bird. Three pigeons (P9131, P452 and P960) had experience with testing without ITI (inter-trial intervals) and many-to-one mappings, three other pigeons (PG47, P069 and PG39) had experience with testing without ITI but not with many-to-one mapping, and the last two pigeons (P234 and PG29) have never been in experiments without ITI or many-to-one mappings. Reinforcement was adjusted individually to avoid feeding outside the testing window of the day, varying from 2.5s to 6s.

Materials

Four operant chambers (Med Associates Inc.) were used for data collection. The chambers, with dimensions 34 x 32 x 35cm (height, length, width), had three circular keys arranged horizontally 20.5cm from the floor, in one of the walls. The keys were 8cm apart, center-to-center, each with 2.5cm in diameter. The back and front walls were made of aluminum, and the roof and side walls were made of acrylic. Located below, the feeder was accessible through an opening in the center of the wall 4 cm from the floor, with 6.5cm wide and 6cm high. When activated, it sprang to an opening in the wall and a 2.8-V, 0.04-A small lightbulb illuminated the food during reinforcement time. The chamber is enclosed in a

cabinet that isolates the animal during the experiment, equipped with a fan that facilitates air circulation. Events that took place in the chamber were programed using ABET II software (Lafayette Instruments).

Procedure

Training

The animals were trained in a Symbolic Matching-to-Sample task with three temporal samples, 2, 6 and 18s, and two comparisons. Stimuli were presented through an illumination on the central keys that corresponded to the duration of one of the samples (e.g., 2, 6 or 18 seconds). Afterwards, comparisons were displayed on the sides with different colors. Each key could be illuminated green or red. Half of the participants were reinforced when the red key was pressed followed by the 2-s sample or when the green key was pressed followed by the 6 or 18-s sample; in the other half, the opposite mapping was reinforced. In both cases, the short duration (2s) was associated with one comparison (C1) and the long durations (6 and 18s) were associated with the other (C2). During training, when a correct response was given, the comparisons turned off and the feeder activated to enable reinforcement. Once the reinforcement ended, the feeder was deactivated, and the next sample was presented. In the case of a wrong response there was a correction procedure in which birds were forced to give a correct response, in order to proceed to the next trial. In these cases, the same sample was presented repeatedly without reinforcement, until the correct response was given. After three wrong responses, only the correct comparison was presented to facilitate the correct discrimination.

A training session consisted of 64 trials, not counting correction trials. The 2-s sample was presented in 32 trials, the 6-s sample in 16 trials, and the 18-s sample in 16 trials. Comparisons (red or green) were displayed the same number of times in each location (right or left) semi-randomly. The pigeons started the training sessions at approximately 85% of their free-feeding weight. Training ended when they obtained 80% of correct answers in all samples for two consecutive days, with a minimum of 15 days of training. In case the criterion was not met for 30 days, the standards were lowered to an average of 70% of correct responses on the last two days, on each sample. After the pigeons met the new criteria, they started the Dark Delay Test.

Dark Delay Test

Delays spent in darkness, with durations of 2.5, 5, 10 and 20s, were inserted between the end of the sample and the beginning of the comparisons. Each session consisted of 80 trials: 48 training (24 x 2s, 12 x 6s, 12 x 18s) – identical to the training phase – and 32 delay trials (16 x 2s, 8 x 6s, 8 x 18s). Reinforcement was administered randomly after a response, with the restriction that half of trials were reinforced. After 5 sessions the pigeons advanced to the Generalization Test.

Generalization Test

A generalization session had 64 trials: 48 trials identical to the training phase (24 x 2s, 12 x 6s, 12 x 18s) and 16 generalization trials where a 3.46-s sample and a 0-s sample were presented (8 x 3.46s, 8 x 0s). To reduce learning new behaviors in the generalization trials, reinforcement was administered semirandomly after a response, with the restriction that half of the generalization trials contained reinforcement. After 5 sessions the pigeons passed to the Lit Delay Test.

Lit Delay Test

The procedure in the Lit Delay Test was identical to the Dark Delay Test except for the delays that were now lighten by the houselight in the operant chamber. After 5 sessions the pigeons proceeded to the New Sample-Delay Test.

New Sample-delay Test

The New Sample-delay Test had 88 trials with old samples (2, 6 and 18s) and new samples (3.46s blue and white hue). In training trials, trained samples were presented 48 times, always without delays (2s x 24, 6s x 12, 18s x 12). In test trials, new samples were presented 40 times in which eight had no delays (3.46s x 4 (blue), 3.46s x 4 (white)) and the remaining 32 trials (3.46s x 16 (blue), 3.46s x 16 (white)) had delays. As in previous tests, reinforcement was deterministic in training trials and semirandom in test trials. Once pigeons finished five sessions of the New Sample-delay Test, the experiment was terminated.

Data Analysis

We used the percentages of correct responses and percentages of choosing the "default" option for the analysis. All the statistical analysis were calculated with the R programing language for statistical computing and graphing, version 4.4.1. To perform the statistical tests, we used ANOVA tests in the delay tests (both darken and illuminated). For the remaining tests we used 95% Confidence Interval and t-tests to compare results with the indifference value (one-sample t-test) and with other values from the same test (paired two-sample t-test), with a Type-1 error of 0.05 for ANOVA and t-test tests. For the regression analysis in the discussion, the sum of squared errors (SSE) was used as a metric to adjust the model's parameters to the best fitting values. To measure the correlation between predicted and observed values we used a test of variance (R^2).

Results

Training

Six out of eight pigeons (P452, PG29, PG39, P234, P069 and P960) met the criterion of 80% of correct responses on each sample, for two consecutive sessions, with an average of 19 sessions (SD = 5.62). Given that PG47 and P9131 failed to meet the criterion in 30 sessions, a slightly more lenient criterion was adopted (75% mean correct responses, for the last two consecutive sessions). Pigeon PG47 met the new criterion in the 32° session and P9131 did it in the 30° session (SD = 1.41).

Dark Delay Test

When dark delays were introduced, the functions started to deviate. The 6 and 18-s functions (associated with C2) remained stable and high across delays, respectively converging to 85% and 80% of correct responses, at the 20-s delay. The 2-s function decreased abruptly with the presentation of the shortest delay (from 77% to 39%) and maintained low levels of correct responses on the rest of delays (approximately 24%) (Fig. 3, left panel). Firstly, we analyzed the 6 and 18-s functions. A two-way repeated-measures ANOVA, with sample as a factor with 2 levels (6 and 18s) and delay as a factor with 5 levels (0, 2.5, 5, 10 and 20s), revealed no significant effect in the sample main effect ($F(1, 7) = 4.52$, $p = .071$, $\eta_G^2 = 0.069$),no significant effect in the delay main effect ($F(4, 28) = 1.87$, $p = .144$, $\eta_G^2 = 0.056$) and no significant effect in the interaction effect ($F(4, 28) = 2.19$, $p = .097$, $\eta_G^2 = 0.061$), showing that the 6 and 18-s samples were treated the same manner. Thus, these functions were averaged for the rest of

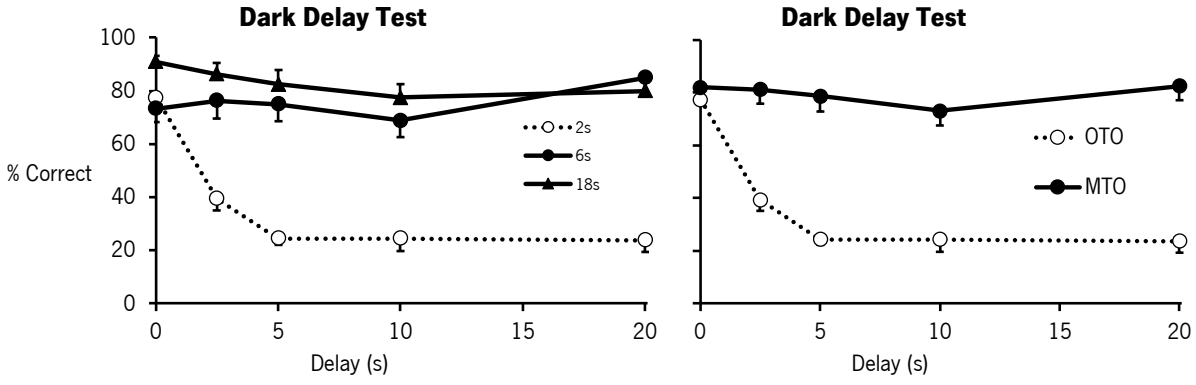
the analysis in the form of a many-to-one function (MTO) and the 2-s sample was renamed to one-to-one function (OTO) (Fig. 3, right panel).

Analyzing the MTO and OTO functions, a two-way repeated-measures ANOVA, with sample as a factor with 2 levels (OTO and MTO), and delay as a factor with five levels (0, 2.5, 5, 10 and 20s), showed a significant main effect of sample ($F(1, 7) = 58.08$, $p < .001$, $\eta_G^2 = 0.790$), a significant main effect of delay ($F(4, 28) = 36.97$, $p < .001$, $\eta_G^2 = 0.520$) and a significant interaction effect ($F(4, 28) = 23.58$, $p < .001$, $\eta_G^2 = 0.447$), showing that the samples associated with the "default" option (C2), and the sample associated with the "single-code" option (C1), were treated differently with the implementation of the delay.

Converting the Delay Test graph to percentages of choosing the "default" option (Fig. 4), reveals the MTO and OTO functions converged at high percentages of "default" in delay trials. Additionally, all eight pigeons showed a significant preference for C2, with 95% Confidence Intervals (CI) = [73.1%, 77.8%], above 50%. In sum, with delays, birds chose mostly C2 (the "default" option), regardless of the sample presented, and the 6 and 18-s functions did not deviate in a significant manner.

Figure 3

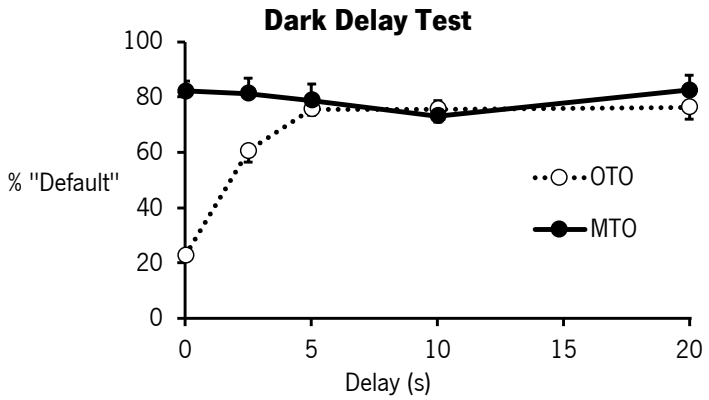
Dark Delay Test results with mean percentages of correct responses (y-axis) in function of the delay (x-axis)



Note. Left panel depicts three samples (2, 6 and 18s). Right panel depicts the 2-s function (one to one, OTO) and the 6 and 18-s functions average (many to one, MTO). Both panels with standard error bars.

Figure 4

Delay Test in percentages of choosing the "Default" option



Note. Dashed line depicts the 2-s function (OTO) and the solid line depicts the 6 and 18-s functions average (MTO). With standard error bars.

Generalization Test

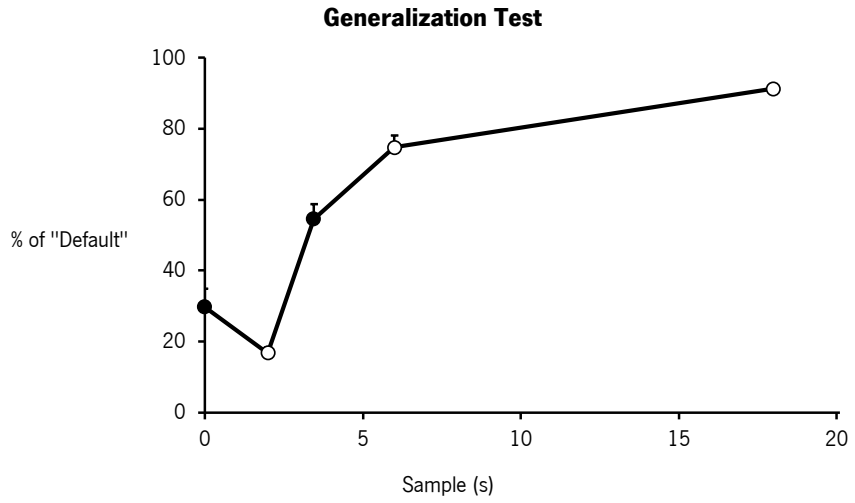
To assess that the birds' level of performance did not diminish due to lack of retraining, first we analyzed the percentages of correct responses in training trials. Comparing the levels of correct responses for each trained sample (2, 6 and 18s) with the indifference value (50%), a one-sample t-test (one tailed) showed that pigeons were capable to perform the task with precision above chance levels for the 2-s sample (M = 83.20, SD = 4.57), $t(7)$ = 20.52, p < .001, d = 7.25; the 6-s sample (M = 74.79, SD = 9.44), $t(7)$ = 7.42, p < .001, d = 2.62; and the 18-s sample (M = 91.25, SD = 3.18), $t(7)$ = 36.68, p < .001, d = 12.97. Confirming that the birds were capable of above random discrimination.

Fig. 5 shows the results of the generalization test in percentages of choices on the "default" option (C2). The 2-s sample had 17% of choices, and the samples associated with the "default" option, 6 and 18s, had 75% and 91%, respectively. Choices following new samples (0 and 3.46s) differed. The 0-s sample, with 30%, showed percentages closer to the 2-s sample than to the 6 and 18-s samples. A paired t-test, comparing 0 and 2s, showed no significant differences between those proportions, $t(7)$ = 2.32, p = .052, d = .823. In the same vein, percentages of choosing the "default" option were significantly less that the indifference level, 95% CI = [24.7, 34.7]. Conversely, the 3.46-s sample had values close to the indifference levels (54%), which was not significantly different from 50%, 95% CI = [48.9, 59.8]. The

pattern of responses for new samples seems to be generalized to the closest durations learned during training, instead of being treated as different by the default rule: comparing the percentages of both new samples, with the average percentages of the "default" samples, shows that the discrepancies between these percentages were significantly different, for the no-sample, $t(7) = -9.45$, $p < .001$, $d = -3.34$, and the 3.46-s sample, $t(7) = -5.28$, $p = .001$, $d = -1.87$. Thus, the psychometric function derived from the Generalization Test implies that pigeons are generalizing the new samples to their temporal neighbors.

Figure 5

Generalization Test results with mean percentages of choosing the "Default" option (y-axis) for trained samples (white circles) and new samples (dark circles) in the x-axis



Note. Variability depicted with standard error bars.

Lit Delay Test

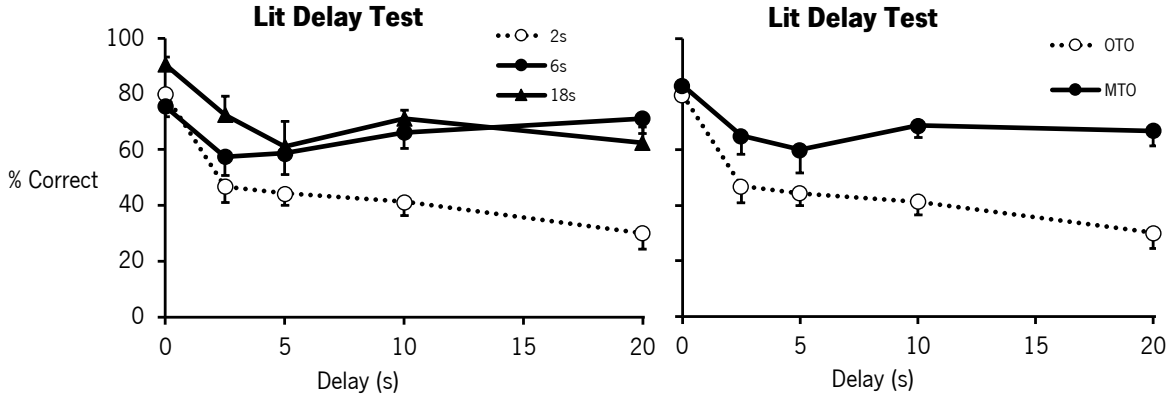
In the Lit Delay Test there were trials with and without delays. Analogous to the Generalization Test, we analyzed the proportions of correct responses on trials without delays to ensure that pigeons were performing the task at higher-than-average levels of correct responses: three one-sample t-tests (one-tailed) showed that pigeons were performing the task at levels higher-than-chance for the 2-s sample ($M = 79.87$, $SD = 6.70$), $t(7) = 12.39$, $p < .001$, $d = 4.38$; the 6-s sample ($M = 75.62$, $SD = 10.86$), $t(7) = 6.67$, $p < .001$, $d = 2.36$; and the 18-s sample ($M = 90.62$, $SD = 7.52$), $t(7) = 15.27$, $p < .001$, $d = 5.40$.

In lit delay trials, for the shortest delay (2.5s), percentages of correct responses decreased similarly for all samples. However, as delays became longer, the percentages for the 6 and 18-s samples

plateaued at 59% and 61%, followed by an increase at longer delays (71% and 63%, respectively, at 20-s delays). On the other hand, the 2-s sample continued to decrease for the remaining delays, with 30% of correct responses at the longest delay (Fig. 6, left panel). Concerning the 6 and 18-s functions, a two-way repeated-measures ANOVA with sample as a factor with two levels (6 and 18s) and delay as a factor with five levels (0, 2.5, 5, 10, 20s) revealed no significant difference in the samples main effect, $F(1, 7) = 4.14$, $p = .081$, $\eta_G^2 = 0.032$, a significant difference in the delay main effect, $(4, 28) = 5.55$, $p = .002$, $\eta_G^2 = 0.196$, and no significant interaction between factors, $F(4, 28) = 2.64$, $p = .055$, $\eta_G^2 = 0.074$. The sample and interaction main effects were not significant, indicating that pigeons react similarly to the 6 and 18-s sample, thus we averaged these functions (Fig. 6, right panel). A two-way repeated-measures ANOVA, with sample as a factor with OTO and MTO as levels, and delay as a factor with five levels (0, 2.5, 5, 10 and 20s), showed a significant main effect of sample ($F(1, 7) = 7.73$, $p = .027$, $\eta_G^2 = 0.373$), a significant main effect of delay ($F(4, 28) = 34.61$, $p < .001$, $\eta_G^2 = 0.444$) and a significant effect of interaction ($F(4, 28) = 5.64$, $p = .002$, $\eta_G^2 = 0.157$), showing that the sample associated with the OTO mapping was treated differently from the samples associated with the MTO mapping in delay trials. Though less pronounced, functions in this test followed responses expected by a single-code/default strategy, maintaining the key pattern of asymmetrical forgetting. Furthermore, five pigeons (P069, P234, P452, PG29, PG47) showed a preference for the option associated with the default code (C2), while three showed levels of indifference (P960, P9131, PG39). But overall, in lit delay trials, there was a significant preference for C2, 95% CI = [59.6%, 64.9%] (Fig. 7).

Figure 6

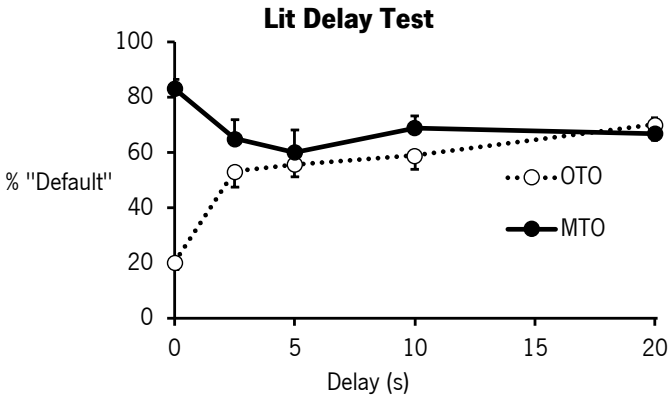
Lit Delay Test results with mean percentages of correct responses (y-axis) in function of the delay (x-axis)



Note. Left panel depicts three samples (2, 6 and 18s). Right panel depicts the 2-s function (OTO) and the 6 and 18-s functions averaged (MTO). Both graphs with standard error bars.

Figure 7

Lit Delay Test in percentages of choosing the "Default" option



Note. Dashed line depicts the 2-s function (OTO) and the solid line depicts the 6 and 18-s functions average (MTO). With standard error bars.

New Sample-delay Test

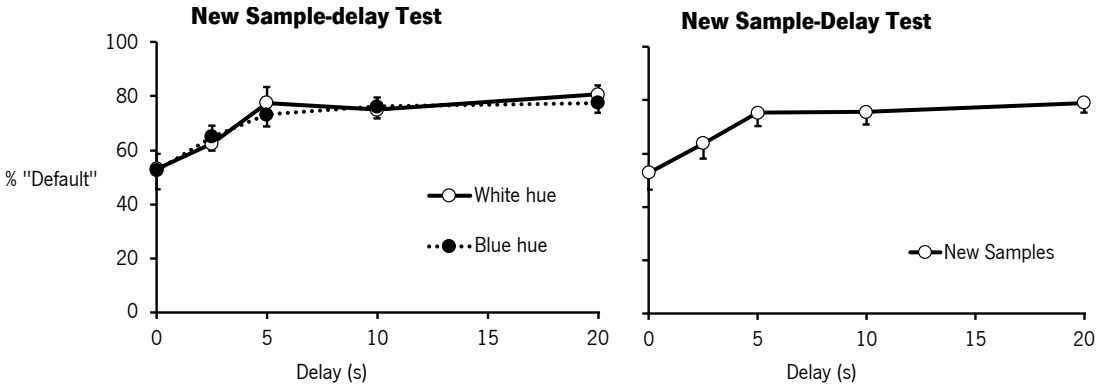
In the New Sample-delay Test two new samples – a 3.46-s sample with a white hue, and a 3.46-s sample with a blue hue – were presented with trained samples in trials without delays. Trained samples had percentages of correct responses significantly above chance levels (2s sample: M = 76.66, SD = 8.33, $t(7)$ = 9.05, p < .001, d = 3.20; 6s sample: M = 76.87, SD = 10.59, $t(7)$ = 7.17, p < .001, d = 2.54; 18s sample M = 91.45, SD = 4.99, $t(7)$ = 23.47, p < .001, d = 8.30), showing that pigeons were still capable of above random discrimination in the last test.

Fig. 8 (left panel) shows the percentages of choices on the "default" option for the new samples. Primarily, the functions of the blue and white hue samples overlap, indicating they are perceived the same way, regardless of hue. Confirming this, a two-way repeated-measures ANOVA with sample as a factor with two levels (3.46s blue and 3.46s white) and delay as a factor with five levels (0, 2.5, 5, 10, 20s), showed a non-significant sample main effect, $F(1, 7)$ = 0.12, p = .733, η_G^2 = 0.001, a significant delay main effect, $F(4, 28)$ = 12.37, p < .001, η_G^2 = 0.333, and non-significant interaction effect, $F(4, 28)$ = 0.200, p = .936, η_G^2 = 0.009. Therefore, the functions were averaged into a "New Samples" function depicted in Fig. 8 (right panel).

At the shortest delay (0s), the percentages started at indifference levels (53%), as the delay increased, percentages for new samples also increased, with 64% at 2.5-s delay, and 75% at 5-s delay. For the rest of delays, percentages remained similar, with 75% at 10-s delay and 79% at 20-s delay. A repeated-measures ANOVA with delay as a factor with five levels (0, 2.5, 5, 10, 20s) showed that the delay influenced percentages of choosing the "default" option, $F(4, 28) = 12.4$, $p < .001$, $\eta_G^2 = 0.439$. Comparing percentages in trials without delays (95% CI = [47.3%, 58.3%]) with delay trials (95% CI = [71.0%, 75.9%]), we see that delay main effect was caused by a significant increase in delay trials. Overall, the New Sample-delay Test showed that at 0-s delays, pigeons were indifferent to the options; in delay trials they showed a preference for the comparison associated with the default code.

Figure 8

New Sample-delay Test results in percentages of choosing the "Default" option (y-axis) in function of the delay (x-axis)



Note. Left panel shows the 3.46-s blue hue sample (dark circles) and the 3.46-s white hue sample (white circles). Right panel shows the average function of the blue and white hue samples. Both panels with standard error bars.

Discussion

This study investigated which strategies pigeons use to learn a Symbolic Matching-to-Sample task with a many-to-one mapping of three samples and two comparisons, where the 2-s sample was associated with C1, and the 6 and 18-s samples were associated with C2. To solve this temporal problem, animals could use a multiple-coding strategy, creating a code for each association. Or they could be more sophisticated, realize two samples were associated with the same comparison and use the single-

code/default strategy to create a code for the lone association (2s), and a default rule that was applied whenever the sample presented was different from 2s.

To answer this question, we used four tests that investigated the strategies through different lenses. The Dark Delay Test used the pattern of responding when the sample information is lost. Predicting that the functions associated with each sample should decrease similarly with delays in case of a multiple-coding strategy, or asymmetrically, with a preference for the "default" comparison, in case of a single-code/default strategy. Results showed characteristic functions predicted by the single-code/default hypotheses: correct responses for the "default" samples remained high and stable throughout the delay and the "single-code" sample decreased below levels of indifference. (Additionally, the 6 and 18-s functions did not deviate in a significant manner.) Furthermore, re-plotting the delay test with percentages of choosing the "default" comparison (Fig. 4), showed that the 2-s sample as the same percentages as the 6 and 18-s samples in longer delays. Corroborating the principle that, once pigeons forget, the default rule activates to treat all the samples the same manner. Overall, the Dark Delay Test suggests the use of single-code/default.

On a similar topic, the abrupt decrease of the 2-s function on shorter delays, and stabilization on longer delays, can also be informative to study the strategy in use. If we consider that the 2-s function is the result of forgetting processes, it would be expected to find a typical forgetting function. In which the rate of forgetting is high at the beginning of a retention interval and slows over time, resulting in a function with a gradual form. However, previous studies on the matter found a step function for the 2-s sample in delay trials, where percentages of correct responses fell to the lowest value in the shortest delay, indicating pigeons were using different rules to respond (see Pinto & Machado, 2015, Retention Test discussion). Although the 2-s function in this study is not a step function, it also has an abrupt decrease in the shortest delay. Thus, to investigate if the 2-s function could be attributed to memory processes, we fitted a negatively accelerated function that is ubiquitous in modeling forgetting. Namely, an exponential decay function (Hunt, 2006, pp. 73 – 75). Let $R(t)$ denote the percentage of recall, R, as a function of delay, t:

$$R(t) = R_0 e^{-m\sqrt{t}}$$

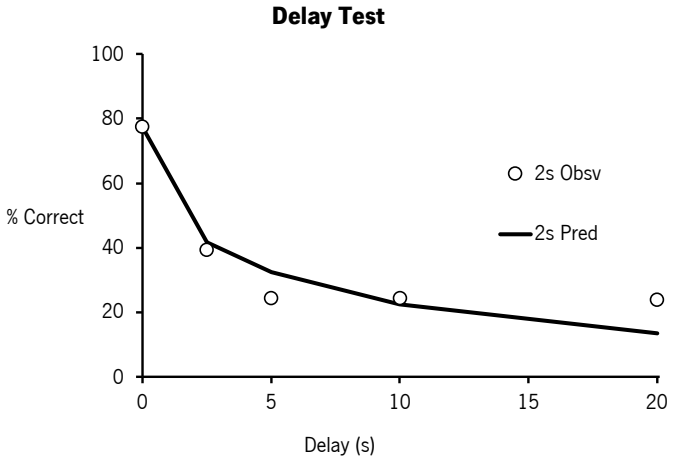
Where R_0 represents the percentage of correct responses at t = 0, or the maximum recall without delay (in this case R_0 is the observed value in the Delay Test, 77%). The term $e^{-m\sqrt{t}}$ represents

the decay factor, where e is approximately 2.71828, m is a constant that represents the rate of forgetting, and t is the delay duration. This equation, firstly, embodies the empirically observed pattern of rapid initial forgetting followed by slower decline at longer delays, a curvilinear form that has been found in several memory experiments with long-term memory in humans (e.g., Wagenaar, 1986) and short-term memory in pigeons (e.g., Wixted & Ebbesen, 1991, Experiment 3), going back to the Ebbinghaus's experiments on savings. Secondly, the equation was taken from a meta-analysis where they analyzed 210 data sets in forgetting, with 105 different models, in which $R(t)$ was one of the best fitting models (Rubin & Wenzel, 1996).

Evaluating the goodness of fit, we used a regression analysis to estimate the best parameter for the decay constant, m. After obtaining the fitted parameter (m = 0.37), the exponential decay model explained approximately 92% of the variability of the original data (R^2 = 0.919) (Fig. 9). Hence, given the model's high goodness-of-fit, the abrupt lack of precision of the 2-s sample on short delay trials was most likely due to memory loss.

Figure 9

Delay test with the observed values from the 2-s sample (white circles) and the predicted values from the exponential model (solid dark line)



By removing the ITI, which could operate as a confound, pigeons still manifested responses expected by a single-code/default strategy. That said, we acknowledge that pigeons could use other salient stimulus to measure time apart from the ITI and sample durations; the reinforcement, which is arguably the most salient stimulus of the entire process for a pigeon, could still be used instead of the ITI

as a “start marker”. This would simulate the single-code/default functions by preferring long durations. To account for this possibility, future studies should invert the mapping used in this investigation to see if pigeons would also prefer long durations (i.e., 2 and 6s to C1; 18s to C2).

In the Lit Delay Test, we investigated if the content of the delay would affect the strategy being employed by comparing the responses with the Dark Delay Test. The test showed that, initially, the percentages of correct responses decreased for all samples, and on longer delays, the OTO and MTO function deviated from each other (Fig. 6, right panel). This pattern was similar to the single-code/default functions seen when the delay was darkened (Fig. 3, right panel). Additionally, pigeons showed a significant preference for the “default” option in delay trials (Fig. 7), which is in line with a single-code/default. When presented with a new light, on a procedure that was until that moment played in darkness, the light probably acted as a disruptive stimulus, deteriorating correct responses, while animals used the single-code/default strategy to respond – as implied by commonalities with the functions in the Dark Delay Test. Thus, the light on lit delay trials did not change response patterns as has been found in other studies (Soares et al., 2025). Pigeons continued to show patterns of responding in favor of a single-code/default strategy.

In the Generalization Test we used the bisection point between 2 and 6s, and no-samples to investigate how pigeons would react to new samples. Proposing that, if the 3.46-s sample has high percentages of choosing “default”, they would be using a single-code/default strategy. If the percentages of choosing “default” were close to indifference levels, they could be using a multiple-coding or single-code/default strategy. Additionally, no-samples were added to investigate if a 0-s sample would elicit a “default” response. Results show that the percentages of 3.46-s were close to indifference levels (54%), which could be the result of a multiple-coding or a single-code/default as a result of generalization processes. The no-sample had percentages close to the 2-s sample (the closest duration on the continuum), but there was a slight increase in percentages of choosing default, suggesting that exist a discontinuity between this sample and the 2-s sample. This could happen because, contrary to the bisection point, the 0-s sample does not exist, making it functionally different from all the others pigeons have seen. This would cause a generalization decrement due to the absence of a sample, and lead to the increased found in the generalization test. Furthermore, this pattern has been found in other generalization tests that use no-samples (e.g., Pinto & Salgado, 2023). Thus, the percentages of choosing the “default” option on no-sample trials indicate that is treated as a sample that exists on the temporal continuum and generalized to its closest duration learn in training, the 2-s sample. On the whole, the

pattern found in this test suggest that the new samples were generalized to the closest durations on the temporal continuum.

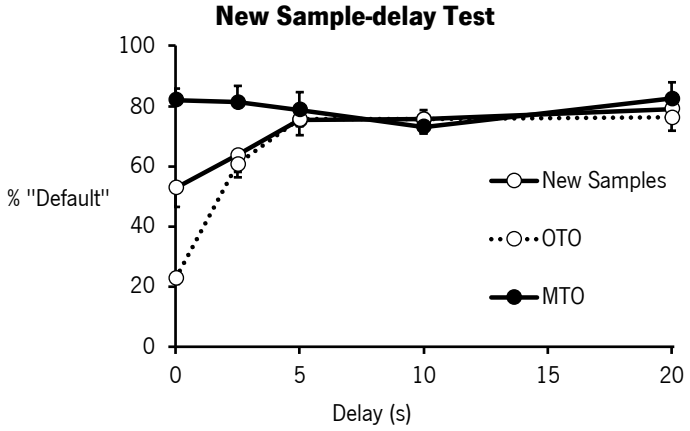
The response dynamics encountered in the Generalization Test could be the result of both multiple-coding and single-code/default strategizing. We find that interpreting these results through the single-code/default hypothesis is a more parsimonious explanation than assuming that pigeons use one strategy for delay tests and another for the Generalization Test.

Lastly, the New Sample-delay Test introduced two bisection points of 3.46s (marked by blue and yellow hues) to assess if samples that are different in appearance from the sample associated with the single-code rule (2s) would elicit a "default" response. Additionally, delay trials were merged with the presentation of new samples as an exploratory procedure. Firstly, the percentages of choosing "Default" were similar to both samples, revealing that pigeons ignore the hue color and prioritize the sample duration, mimicking the behavior learned during training. Secondly, the new samples had indifference values at 0-s delays, showing that samples that are different in appearance from the 2-s sample did not elicit a "default" response. And thirdly, on delay trials, pigeons showed a preference for the comparison associated with the default rule. This test as a whole uncovers an interesting pattern that can help disentangle the results found in the Generalization Test.

In the New Sample-delay Test, trials without delays – which in essence are identical to generalization trials – had indifference values. As stated previously, this pattern could be the result of multiple-coding or single-code strategies in trials without delays. Conversely, in delay trials, percentages of choosing the "default" option increased, which could be explained by a single-code/default strategy. A plausible explanation to account for this pattern as a whole is that pigeons use the single-code/default throughout the procedure, and the indifference values found in Generalization Test are caused by generalization processes. In other words, pigeons perceive the 3.46-s sample as "equal to 2s" in some trials and "different from 2s" in other trials, leading to values close to 50%. In trials with delays, the sample information is lost, and the default rule is activated to respond, resulting in higher percentages of choosing the "default" option. Thus, this explanation reinforces the interpretation of the Generalization Test results through the single-code/default lenses.

Figure 10

New Sample-delay Test results, in percentages of choosing the "Default" option (y-axis) in function of the delay (x-axis) with the OTO and MTO functions from the Dark Delay Test superimposed



Furthermore, adding the OTO and MTO functions from the Dark Delay Test to the New Sample-delay Test graph (Fig. 10) reveals that the functions overlap in delay trials. This supports the previous point by showing that pigeons not only prefer the "default" option with the 3.46-s sample, but also have the same magnitude found in the Dark Delay Test, which had results in line with a single-code/default. Additionally, the proximity of the functions suggests that once the sample information is lost, the default rule is activated to treat all the samples the same manner regardless of the test, which is also a pattern in favor of a single-code/default.

In this experiment we tried to attain which strategies pigeons use when learning a temporal matching-to-sample task. In conclusion, the Dark Delay Test and the Lit Delay Test provided evidence in favor of the single-code/default hypothesis. The Generalization Test had inconclusive results that could be explained by a single-code/default or multiple-coding strategy. However, the New Sample-delay Test, coupled with results from delay tests, favors the single-code/default interpretation for the Generalization Test results. Considering all this information, we conclude that pigeons can use the single-code/default as a learning strategy.

Nonetheless, some results are incongruent with the single-code/default principles. The single-code/default states that when a sample information is lost, animals ought to respond with the default code because the lack of memory is different from the 2-s sample. From this, it follows that choices on the "default" comparison should increase in longer delays, compared to shorter delays, as the likelihood

of forgetting increases. However, functions depicting the percentages of choosing “default” in tests with delays remained similarly valued from the 5-s delay to the 20-s. To account for this incongruency, the single-code/default strategy should be revised with the elaboration of additional principles for future studies.

References

Gaitan, S. C., & Wixted, J. T. (2000). The role of "nothing" in memory for event duration in pigeons. *Animal Learning & Behavior, 28*(2), 147–161. https://doi.org/10.3758/BF03200250

Hunt, E. (2006). *The mathematics of behavior.* Cambridge University Press. https://doi.org/10.1017/CBO9780511618222

Pinto, C., & Machado, A. (2015). Coding in pigeons: Multiple-coding versus single-code/default strategies. *Journal of the Experimental Analysis of Behavior, 103*(3), 472–483. https://doi.org/10.1002/jeab.153

Pinto, C., & Machado, A. (2017). Unraveling sources of stimulus control in a temporal discrimination task. *Learning & Behavior, 45*(1), 20–28. https://doi.org/10.3758/s13420-016-0233-2

Pinto, C., Queiroz, J. (2024). Exploring boundary conditions of the single-code/default strategy in pigeons. *Learn Behav 52*, 302–314 (2024). https://doi.org/10.3758/s13420-024-00629-0

Pinto, C., & Salgado, S. (2023). Searching for nothing: placing zero on the temporal continuum. *Animal Cognition*, *26*(4), 1209-1216. https://doi.org/10.1007/s10071-023-01770-5

Rubin, D. C., & Wenzel, A. E. (1996). One hundred years of forgetting: A quantitative description of retention. *Psychological Review, 103*(4), 734–760. https://doi.org/10.1037/0033-295X.103.4.734

Singer, R. A., Klein, E. D., & Zentall, T. R. (2006). Use of a Single-Code/Default Strategy by Pigeons to Acquire Duration Sample Discriminations. *Learning & Behavior, 34*(4), 340–347. https://doi.org/10.3758/BF03193197

Soares, C., Santos, M., & Pinto, C. (2025). Is choice bias in delayed matching a consequence of inter-trial interval effects? *Behavioural Processes, 226,* 105 - 153. Elsevier. https://doi.org/10.1016/j.beproc.2025.105153

Spetch, M. L., & Wilkie, D. M. (1982). A systematic bias in pigeons' memory for food and light durations. *Behaviour Analysis Letters, 2*(5), 267–274.

Spetch, M. L., & Wilkie, D. M. (1983). Subjective shortening: A model of pigeons' memory for event duration. *Journal of Experimental Psychology: Animal Behavior Processes, 9*(1), 14–30. https://doi.org/10.1037/0097-7403.9.1.14

Wagenaar, W. A. (1986). My memory: A study of autobiographical memory over six years. *Cognitive Psychology, 18*(2), 225–252. https://doi.org/10.1016/0010-0285(86)90013-7

Wixted, J. T., & Ebbesen, E. B. (1991). On the form of forgetting. *Psychological Science, 2*(6), 409–415. https://doi.org/10.1111/j.1467-9280.1991.tb00175.x

Appendix

Autorização da Comissão de Ética

A presente tese ("Multiple-coding vs. Single-code/Default: Analysis of Learning Strategies in Pigeons") fez parte de um projeto de investigação intitulado "Comportamento animal e adaptação ao ambiente: discriminação temporal, escolha e raciocínio causal" que foi submetido e aprovado internamente pela Subcomissão de Ética para as Ciências da Vida e da Saúde (SECVS; documento SECVS 044/2017) e externamente pela Direção Geral de Alimentação e Veterinária (DGAV; autorização #024946). De acordo com o Decreto-Lei n.º 113/2013 de 7 de agosto, a autorização legal de projetos de investigação/experimentação animal é feita pela DGAV.

O Orientador,

