



Sample-comparison mapping and joint stimulus control

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ABSTRACT

A matching-to-sample task with a 3-sample, 2-comparison mapping has been found to engender joint control by the stimuli that signaled the samples (keylight) and the inter-trial interval (houelight), with a trade-off in the degree of control exerted by each stimulus. To learn about the boundary conditions for the establishment of that joint stimulus control, we trained pigeons in a similar task, but featuring a one-to-one sample-comparison mapping, with two samples and two comparisons. To assess their relative influences, we ran two tests where each of the stimuli was removed: in one test, no sample keylight was presented, and in the other, the ITI was spent in darkness. Results were consistent with both stimuli influencing choice but there was no clear evidence of a trade-off between them. These results suggest that sample-comparison mapping and/or total number of samples may influence how an animal directs its attention to the stimuli available.

1. Introduction

At any given moment, a wealth of stimuli surrounds an organism and adapted behavior requires identifying which stimuli (and stimulus dimensions) are relevant (e.g., Kamin, 1968; Leith and Maki, 1975; Mackintosh, 1965; Sutherland and Mackintosh, 1971; Wagner et al., 1968). Additionally, selectivity regarding which stimuli are attended to is a necessity given the limits in attentional capacity (Pashler, 1998) and, while attention may be shared, the processing of each single dimension suffers (e.g., Kraemer and Roberts, 1985; Langley and Riley, 1993; Maki and Leith, 1973). Despite these limitations, when there are redundant cues and attending to only one would be sufficient to learn a task, animals may nevertheless attend to more than one cue (e.g., Cheng et al., 1996; McMillan and Roberts, 2010; Meck and Church, 1983; Roberts and Mitchell, 1994). In some cases, when attention is divided between stimuli, there is a trade-off in their relative influences: The more one stimulus controls responding, the less others do (e.g., Gottselig et al., 2001; Kirkpatrick-Steger and Wasserman, 1996; Vyazovska et al., 2014).

One example of attentional trade-off came from a series of studies focused on coding flexibility (Pinto et al., 2017; Pinto and Machado, 2015; 2017). Pigeons learned an asymmetric matching-to-sample task with three samples (white keylight lasting 2, 6, or 18 s) mapped onto two comparisons (a red and a green keylight). One comparison was correct following 2-s samples, and the other following 6-s and 18-s samples. Trials were separated by a 30-s, houselight-illuminated, inter-trial interval (ITI). Removing either the white keylight (sample) or the ITI

houelight biased pigeons' choices, suggesting control by both stimuli. On no-sample tests there was a preference for the comparison associated with 2-s samples; on dark-ITI tests accuracy decreased only for 2-s sample trials. Interestingly, the two tests showed a negative correlation: the stronger the preference for "short" on no-sample trials, the lower the accuracy on short-sample trials on dark-ITI tests, suggesting a trade-off in the reliance on sample keylight and ITI houselight.

An open question related to this 3-sample, 2-comparison task regards which task characteristics are required to engender joint stimulus control (e.g., number of samples, the many-to-one mapping, the relative salience of the stimuli). Identifying boundary conditions for different learning strategies is critical to our understanding of learning and adapted behavior, so in this study we used a similar task, but featured a symmetric, one-to-one sample-comparison mapping (two samples, two comparisons). To assess the relative influences of sample and houselight ITI, we ran the same tests as in the many-to-one task. Despite their planned role as a simple trial separator, ITIs often go beyond that, for instance serving as context for the estimation of sample durations, or affecting performance in delay testing (e.g., Kelly and Spetch, 2000; Sherburne et al., 1998; Spetch and Rusak, 1989; Ward and Odum, 2007). Our goals were to assess if the ITI played a role on the learning of this version of the task, and whether joint stimulus control would emerge.

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2. Method

2.1. Subjects

Eight pigeons (*Columba livia*) were maintained at approximately 85% of their free-feeding body weight. They were kept in individual cages, with free access to water and grit, while most food was given as reinforcement during the experimental sessions. The colony room had a 13 h/11 h light-dark cycle, with lights on at 08h00, and the temperature was kept between 20 and 22 °C. All the birds had experience with comparable temporal discriminations and matching-to-sample tasks. The experiment was conducted daily, at approximately the same time for each bird, 6 days a week.

2.2. Apparatus

Four operant chambers were used: three identical Lehigh Valley Electronics (LVE) and one homemade chamber. The LVE chambers measured 34 × 35 × 31 cm (h × l × w) and the response panel features three circular keys, 2.5 cm in diameter, horizontally arranged, 8.5 cm apart, center-to-center. The bottom of the keys distanced 22.5 cm from the wire mesh floor. Each key was equipped with a 12-stimulus Industrial Electronics Engineers (IEE) in-line projector, with a 28-V, 0.1-A lamp for each stimulus. Mixed grain was delivered as a reinforcement through the food-hopper opening, which measured 5 × 6 cm (h × w) and was centered on the response panel, its bottom 8.5 cm above the floor. This opening was illuminated with a 28-V, 0.04-A lamp when the hopper was activated. On the wall opposite the response panel, 30 cm above the floor, a 28-V, 0.1-A houselight provided general illumination. An exhaust fan provided ventilation and masked outside noise. The homemade chamber was similar to the other chambers, differing only in some dimensions: it measured 31 × 33 × 33 cm (h × l × w), the bottom of each key was 21 cm above the floor, and the food hopper opening measured 4.5 × 6 cm (h × w) and was 6.5 cm above the floor. The houselight was in the response panel, 27.5 cm above the floor. The chamber was enclosed in a PVC sound-attenuating case (Med Associates, ENV-018V), equipped with an exhaust fan. Experimental events were controlled via the ABET II software (Lafayette Instrument Company).

2.3. Procedure

2.3.1. Training

All task details were similar to Pinto and Machado (2023), with the exception that, instead of three samples, the present task featured only two samples. A session began with a houselight-illuminated, 30-s inter-trial interval (ITI). The houselight turned off when the ITI ended, and a trial started with the presentation of a white hue on the center key for 2 or 6 s (sample). Following sample offset, a red hue and a green hue were presented on the side keys (comparisons). Choice of each comparison was correct following one of the samples (the correct comparisons were counterbalanced across animals). A peck on either comparison turned both comparisons off. When the correct comparison was chosen, reinforcement was delivered, followed by the ITI. When the incorrect comparison was chosen, the ITI started immediately. A trial with an incorrect choice was repeated; after three consecutive incorrect choices, the trial would repeat for a final time, with only the correct comparison presented (correction procedure). Reinforcement durations were adjusted individually, and ranged from to 2.5–4.5 s.

A session comprised 64 trials, divided in two 32-trial blocks (with 16 2-s and 16 6-s samples). Trials within each block were presented in random order. Comparison location was determined pseudo-randomly, with the constraint that each comparison was presented the same number of times on each side key, in each block. In the first 10 sessions, all correct choices were reinforced. From the 11th session onward, a maximum of 75% of correct choices were reinforced, and the correction procedure was no longer in effect. Training lasted a minimum of 20

sessions, and ended when a minimum of 80% correct responses were made to each sample, for three consecutive sessions, or a maximum of 30 sessions was reached.

2.3.2. Test

Each session comprised 64 trials: 40 training trials, 8 no-sample test trials, and 16 dark-ITI test trials. Training trials (20 × 2-s, 20 × 6-s samples) were the same as in Training, with all correct responses reinforced. In a no-sample trial, the sample was never presented: the end of the ITI was followed immediately by the comparisons. Dark-ITI trials (8 × 2-s, 8 × 6-s samples) were similar to training trials, excepting that their preceding ITI was spent in darkness. Reinforcement was delivered on 50% of test trials, non-differentially. Testing lasted 10 sessions.

2.4. Data analysis

Statistical tests were conducted with the jamovi software for Windows (The jamovi project, 2022), with Type-1 error rate set to 0.05 (R Core Team, 2021). To compare the two tests, we used the same metrics that in previous papers suggested a trade-off between ITI houselight and sample: a) the proportion of “short” choices on no-sample trials (which correlates positively with houselight influence: If houselight recency is associated with “short” choices in training, on no-sample trials there should be a very high proportion of “short” choices), and b) proportion correct on “short” trials with a dark ITI (which correlates positively with sample influence: The stronger the control by the sample, the weaker the impact of ITI manipulations should be, so performance should stay at a high level. Conversely, if houselight recency is associated with “short” choices, the stronger the houselight control, the less “short” choices should occur following a dark-ITI). For a detailed discussion of these metrics, please refer to Pinto and Machado (2023). These metrics were compared via a Pearson’s correlation (Kim, 2015).

A one-sample t-test assessed whether pigeons responded at chance level in no-sample tests. Two-tailed, paired-samples t-tests compared choices when the ITI was dark or illuminated, as well as assessed the predictions of a stimulus-competition model (Pinto and Machado, 2023). For these predictions, an equivalence test was also run (“two one-sided tests” procedure; e.g., Lakens, 2017). For that, a sensitivity analysis in G*Power (version 3.1.9.7; Faul et al., 2007), with power set to 80% and alpha to 0.05 (Lakens, 2014), was used to calculate the smallest effect sizes of interest. The normality assumption was assessed via Shapiro-Wilk tests. For effect size, Cohen’s d_z (the standardized mean difference; see, e.g., Cohen, 1988, p. 48; Lakens, 2013) was calculated. Given that effect size can be the main takeaway from an analysis (e.g., Sullivan and Feinn, 2012), each effect size was complemented with the correspondent 95% confidence interval.

3. Results

Training took an average of 24.75 sessions (range: 20–30). One of the pigeons failed to meet the learning criterion by session 30, but its average accuracy in the last three sessions was fairly high (2 s: 0.83, 6 s: 0.82), and so progressed into testing.

On no-sample trials there was a preference for the “short” comparison, chosen on 75% of the trials (range: 50%–99%), a value significantly above chance (50%): $t(7) = 3.70$, $p = .008$, $d_z = 1.31$, 95% CI [0.32, 2.25]. The effect of the dark-ITI test (Fig. 1) differed between the samples. On the one hand, for 6-s trials (filled bars), accuracy did not differ significantly between training (0.91) and test (0.89) trials, $t(7) = 1.22$, $p = .262$, $d_z = 0.43$, 95% CI [−0.31, 1.14], with performance consistently high for all pigeons. On the other hand, for 2-s trials (empty bars), accuracy decreased substantially between training (0.85) and test (0.58) trials, $t(7) = 8.19$, $p < 0.001$, $d_z = 2.90$, 95% CI [1.25, 4.52].

The two tests are contrasted in Fig. 2: proportion of “short” choices in no-sample trials is plotted against the proportion of correct choices of “short” following a dark ITI. There was no significant correlation

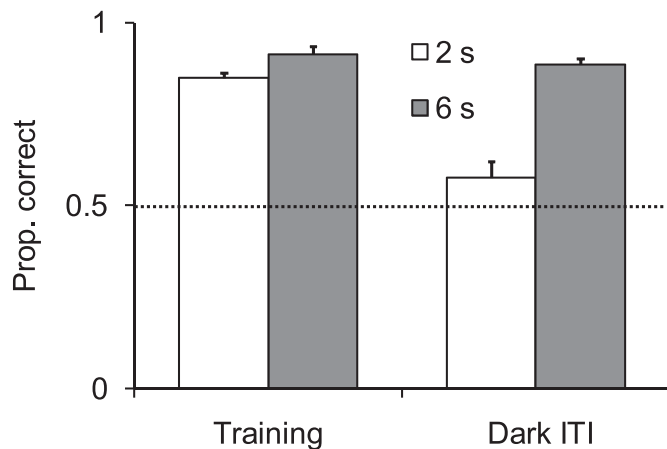


Fig. 1. Average (with standard error of the mean) proportion of correct choices following 2-s (empty bars) and 6-s (filled bars) samples during testing, in training trials (left) and in dark-ITI test trials (right).

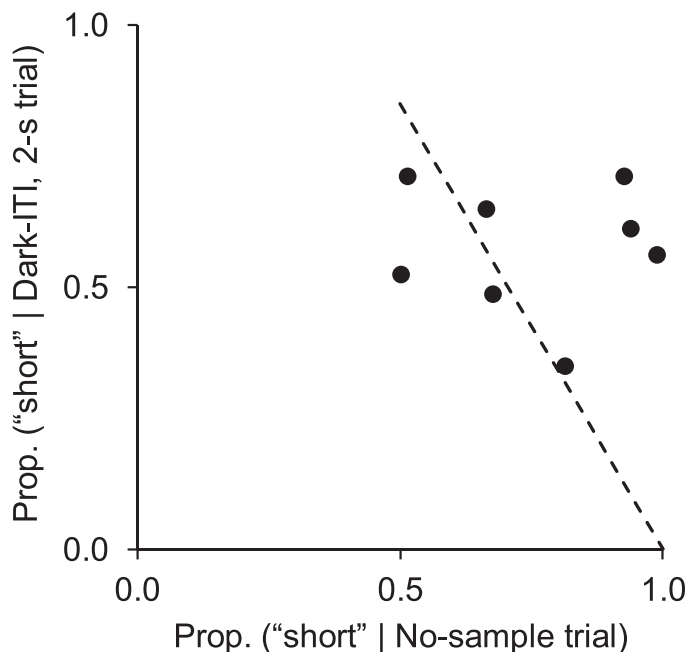


Fig. 2. Proportion of “short” choices in no-sample test trials (X axis) plotted against proportion of correct responses following 2-s samples in dark-ITI test trials (Y axis). Each data point refers to one pigeon. The dashed line refers to the predictions of a model of joint stimulus control (Pinto and Machado, 2023).

between the two measures, $r(6) = -.04$, $p = .931$.

4. Discussion

The no-sample and dark-ITI tests yielded similar results to the 3-sample, 2-comparison task (Pinto et al., 2017; Pinto and Machado, 2023). In the no-sample test, there was a preference for the comparison associated with the short sample, of a similar magnitude to those previous studies (75% vs. 73% and 62%). The finding that manipulating the ITI illumination affected only short-sample trials also replicated the studies with a many-to-one task. The similarities do not hold as strongly when the two tests are compared at the individual level. In the 3-sample, 2-comparison task, the greater the impact of the houselight removal, the lesser the impact of the sample removal was (and vice-versa) – suggesting not only joint control by houselight and sample, but a trade-off in that control. In

the present study, no relation was found between the two tests, which could suggest that if both sample and ITI houselight exerted control over responding, there was no trade-off in this control.

Pinto and Machado (2023) proposed two models where sample keylight duration and houselight trace strength – either conceptualized as in relation to a threshold or as exemplar models – could jointly control responding. Given that the first of those models predicts how performance on the two tests should relate, we present it in Fig. 2 (dashed line). The model posits that each pigeon should fall somewhere along the line (with the location depending on the relative influences of sample keylight and ITI houselight). While some results correspond closely to the predictions, there are some deviations of note, such that, as described earlier, the whole dataset does not show the predicted negative correlation. However, it is worth noting that in Pinto and Machado (2023), even though the model described well most pigeons, there was a subset of animals that, although showing a negative trend, followed a line different from the one predicted. Taking into account the possibility that stimulus trade-off may express itself along different trend lines, the present data, while not showing a pattern consistent with stimulus control trade-off, does not allow us to discard that possibility entirely. Other permutations of the task and further replications may help clarify this question.

The second model estimates the relative associative strengths of sample keylight and ITI houselight and predicts baseline performance. When applied to the present data, the predictions were fairly accurate, not differing significantly from actual performance, $t(7) = 0.24$, $p = .815$, $d_z = 0.09$, 95% CI $[-0.61, 0.78]$. Predictions and observations were also statistically equivalent (the observed effect size, $d_z = 0.09$, was within the equivalence bounds of $d_z = -1.16$ and $d_z = 1.16$, $t(7) = 3.03$, $p = .01$).

The fact that removing the ITI houselight decreased matching accuracy only for short samples could suggest that houselight recency was associated with “short” choices during training. However, if houselight alone controlled responding, this decrease in accuracy should have been more pronounced, so perhaps sample duration also controlled choices in some of the trials. Another possibility is that the pigeons learned the task by attending only to the sample. Even though the beginning of both samples is equally close to the ITI, the end of short samples is closer to the ITI than the end of long samples is, and this proximity may make short samples more vulnerable to changes in ITI conditions – which could lead to the sample differences observed in the dark-ITI test. However, assuming that resistance to these generalization-decrement effects varies among animals, a more resistant pigeon would show high accuracy to short samples in dark-ITI tests, and also, in no-sample tests, a strong preference for “short” (a 0-s sample is closest to the short sample; see also Pinto and Salgado, 2023). That is, the two metrics would be positively correlated. Given that was not the case (see Fig. 2), the pigeons probably did not learn this task by attending solely to the sample.

Future studies may further identify which task characteristics (sample-comparison mapping, number of samples, their durations, etc.) are critical for the adoption of different learning strategies. Exploration of these variables may yield deeper insights into the boundary conditions for learning strategies, and, by extension, into the mechanisms of discrimination learning.

Compliance with ethical standards

The research was carried out in agreement with the European (Directive 2010/63/EU) and Portuguese law (Ordinance 1005/92 of October 23), being approved by the Directorate-General for Food and Veterinary, the Portuguese national authority for animal health (Authorization #024946).

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CRediT authorship contribution statement

Castanheira-Dinis José Miguel: Writing – review & editing, Writing – original draft, Investigation. **Pinto Carlos:** Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

Data availability

The research data can be accessed at [Sample-comparison mapping and joint stimulus control \(Original data\)](#) (dataRepositóriUM).

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References

- Cheng, K., Spetch, M.L., Miceli, P., 1996. Averaging temporal duration and spatial position. *J. Exp. Psychol. Anim. Behav. Process.* 22, 175–182. <https://doi.org/10.1037/0097-7403.22.2.175>.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Lawrence Erlbaum Associates.
- Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* 39, 175–191. <https://doi.org/10.3758/bf03193146>.
- Gottselig, J.M., Wasserman, E.A., Young, M.E., 2001. Attentional trade-offs in pigeons learning to discriminate newly relevant visual stimulus dimensions. *Learn. Motiv.* 32, 240–253. <https://doi.org/10.1006/lmot.2000.1081>.
- Kamin, L.J., 1968. “Attention-like” processes in classical conditioning. In: Jones, M.R. (Ed.), *Miami Symposium on the Prediction of Behavior: Aversive Stimulation*. University of Miami Press, pp. 9–31.
- Kelly, R., Spetch, M.L., 2000. Choice biases in delayed matching-to-sample duration with pigeons: manipulations of ITI and delay illumination. *Q. J. Exp. Psychol.* 53B (4), 309–323. <https://doi.org/10.1080/713932737>.
- Kim, S. (2015). ppcor: Partial and Semi-Partial (Part) Correlation. [R package]. <https://cran.r-project.org/package=ppcor>.
- Kirkpatrick-Steger, K., Wasserman, E.A., 1996. The what and the where of the pigeon's processing of complex visual stimuli. *J. Exp. Psychol. Anim. Behav. Process.* 22, 60. <https://doi.org/10.1037/0097-7403.22.1.60>.
- Kraemer, P.J., Roberts, W.A., 1985. Short-term memory for simultaneously presented visual and auditory signals in the pigeon. *J. Exp. Psychol. Anim. Behav. Process.* 11, 137–152. <https://doi.org/10.1037/0097-7403.11.2.137>.
- Lakens, D., 2013. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front. Psychol.* 4, 1–12. <https://doi.org/10.3389/fpsyg.2013.00863>.
- Lakens, D., 2014. Performing high-powered studies efficiently with sequential analyses: sequential analyses. *Eur. J. Soc. Psychol.* 44, 701–710. <https://doi.org/10.1002/ejsp.2023>.
- Lakens, D., 2017. Equivalence tests: a practical primer for t tests, correlations, and meta-analyses. *Soc. Psychol. Personal. Sci.* 8, 355–362. <https://doi.org/10.1177/1948550617697177>.
- Langley, C.M., Riley, D.A., 1993. Limited capacity information processing and pigeon matching-to-sample: testing alternative hypotheses. *Anim. Learn. Behav.* 21, 226–232. <https://doi.org/10.3758/BF03197986>.
- Leith, C.R., Maki, W.S., 1975. Attention shifts during matching-to-sample performance in pigeons. *Anim. Learn. Behav.* 3, 85–89. <https://doi.org/10.3758/BF03209105>.
- Mackintosh, N.J., 1965. Selective attention in animal discrimination learning. *Psychol. Bull.* 64, 124–150. <https://doi.org/10.1037/h0022347>.
- Maki, W., Leith, C., 1973. Shared attention in pigeons. *J. Exp. Anal. Behav.* 19, 345–349. <https://doi.org/10.1901/jeab.1973.19.345>.
- McMillan, N., Roberts, W.A., 2010. The effects of cue competition on timing in pigeons. *Behav. Process.* 84, 581–590. <https://doi.org/10.1016/j.beproc.2010.02.018>.
- Meck, W.H., Church, R.M., 1983. A mode control model of counting and timing processes. *J. Exp. Psychol. Anim. Behav. Process.* 9, 320–334. <https://doi.org/10.1037/0097-7403.9.3.320>.
- Pashler, H.E., 1998. *The Psychology of Attention*. MIT Press.
- Pinto, C., Machado, A., 2015. Coding in pigeons: Multiple-coding versus single-code/default strategies. *J. Exp. Anal. Behav.* 103, 472–483. <https://doi.org/10.1002/jeab.153>.
- Pinto, C., Machado, A., 2017. Unraveling sources of stimulus control in a temporal discrimination task. *Learn. Behav.* 45, 20–28. <https://doi.org/10.3758/s13420-016-0233-2>.
- Pinto, C., Machado, A., 2023. Trade-offs in joint stimulus control in a temporal discrimination task. *Learn. Motiv.* 84, 101928. <https://doi.org/10.1016/j.lmot.2023.101928>.
- Pinto, C., Salgado, S., 2023. Searching for nothing: placing zero on the temporal continuum. *Anim. Cogn.* 26, 1209–1216. <https://doi.org/10.1007/s10071-023-01770-5>.
- Pinto, C., Fortes, I., Machado, A., 2017. Joint stimulus control in a temporal discrimination task. *Anim. Cogn.* 20, 1129–1136. <https://doi.org/10.1007/s10071-017-1130-6>.
- R Core Team (2021). R: A Language and environment for statistical computing. (Version 4.1) <https://cran.r-project.org>.
- Roberts, W.A., Mitchell, S., 1994. Can a pigeon simultaneously process temporal and numerical information. *J. Exp. Psychol.: Anim. Behav. Process.* 20, 66–78. <https://doi.org/10.1037/0097-7403.20.1.66>.
- Sherburne, L.M., Zentall, T.R., Kaiser, D.H., 1998. Timing in pigeons: the choose-short effect may result from pigeons' “confusion” between delay and intertrial intervals. *Psychon. Bull. Rev.* 5 (3), 516–522. <https://doi.org/10.3758/BF03208831>.
- Spetch, M.L., Rusak, B., 1989. Pigeons' memory for event duration: intertrial interval and delay effects. *Anim. Learn. Behav.* 17 (2), 147–156. <https://doi.org/10.3758/BF03207629>.
- Sullivan, G.M., Feinn, R., 2012. Using effect size—or why the P value is not enough. *J. Grad. Med. Educ.* 4, 279–282. <https://doi.org/10.4300/JGME-D-12-00156.1>.
- Sutherland, N.S., Mackintosh, N.J., 1971. *Mechanisms of Animal Discrimination Learning*. Academic Press.
- The jamovi project (2022). jamovi. (Version 2.3) [Computer Software]. Retrieved from <https://www.jamovi.org>.
- Vyazovska, O.V., Teng, Y., Wasserman, E.A., 2014. Attentional tradeoffs in the pigeon. *J. Exp. Anal. Behav.* 101, 337–354. <https://doi.org/10.1002/jeab.82>.
- Wagner, A.R., Logan, F.A., Haberlandt, K., Price, T., 1968. Stimulus selection in animal discrimination learning. *J. Exp. Psychol.* 76, 171–180. <https://doi.org/10.1037/h0025414>.
- Ward, R.D., Odum, A.L., 2007. Disruption of temporal discrimination and the choose-short effect. *Learn. Behav.* 35 (1), 60–70. <https://doi.org/10.3758/BF03196075>.