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Effects of initial-link schedule on suboptimal choice are modulated by bias

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ABSTRACT

Previous research suggests that longer initial-link durations decrease suboptimal choice, a relationship that has been predicted by the Signal for Good News (SiGN) model. The present study aimed to replicate these results with FR 1 and VI 20-s initial-link durations. Six pigeons responded in a concurrent-chains procedure in which one initial-link key led to a terminal-link which provided a lower overall probability of reinforcement, but included discriminative stimuli that signaled trial outcomes (suboptimal alternative), and the other led to a terminal link with higher overall probability, but did not arrange discriminative stimuli (optimal alternative). Preference for the suboptimal alternative was lower with VI 20-s schedules during initial links compared with FR 1 schedules. Such preference was modulated by key-location biases; suboptimal choice was more extreme when the suboptimal alternative was located on the key towards which pigeons were biased, relative to when it was located on the other key. Overall, predicted values of suboptimal choice from the SiGN model were similar to observed values, although some deviations were apparent due to the key-location biases. These results provide further evidence that initial-link durations influence suboptimal choice and also point to the potential influence of idiosyncratic biases on suboptimal choice.

1. Effects of initial-link schedule on suboptimal choice are modulated by bias

It is generally expected that subjects will emit behaviors that result in more reinforcers (Herrnstein, 1970; Baum; 1974). This is corroborated by theories such as the Law of Effect (Thorndike, 1911). However, growing evidence shows that under some conditions organisms prefer alternatives that provide the *least* overall reward (Dunn and Spetch, 1990). Such *suboptimal choice* appears to depend on whether informative (i.e., discriminative) stimuli signal the availability of reinforcers. In general, organisms prefer alternatives that produce stimuli that differentially signal outcomes (i.e., reinforcer availability or non-availability) over alternatives without discriminative stimuli, even if the former delivers less reinforcers overall. For instance, Stagner and Zentall (2010) found that pigeons preferred a 20% reinforced alternative that produced discriminative stimuli signaling reinforcer availability over an alternative that did not produce such stimuli but delivered reinforcers in 50% of trials (Fig. 1, left panel; see also Gipson et al., 2009; McDevitt et al., 2016; Spetch et al., 1990; Zentall, 2015).

One variable that appears to influence suboptimal choice is the reinforcement schedule arranged during the choice phase. In a concurrent-chains procedure, preference for the suboptimal alternative decreases as more responses are required to make a choice (e.g., as in a fixed-ratio schedule) or when the initial-link duration is longer (e.g., Dunn and Spetch, 1990; Dunn et al., 2024; Kendall, 1974; Pisklak et al., 2019). To explain this, McDevitt et al. (2016) proposed the Signal for Good News (SiGN) model. The model suggests that stimuli signaling reinforcer availability may effectively serve as conditioned reinforcers and hence enhance preference for the suboptimal alternative. This conditioned-reinforcer effect depends on the extent to which the stimuli signal a *reduction* in delay to a reinforcer delivery. Such delay reduction is modulated by temporal context. Put simply, when initial links are short, only the onset of the signal for food in the terminal link on the suboptimal alternative provides more than a slight delay reduction. When initial links are long, terminal-link onset on the optimal alternative also signals a reduction in reinforcer delay and hence serves as a conditioned reinforcer. This reduces the influence of conditioned reinforcement on choice, and concomitantly strengthens the influence of primary reinforcement, increasing optimal choice (Pisklak et al., 2019).

The current experiment replicated previous work demonstrating the

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effects of initial-link duration on suboptimal choice. We arranged a concurrent-chains procedure in which the optimal alternative led to a higher reinforcer probability with nondifferentially signaled outcomes, and the suboptimal alternative led to a lower reinforcer probability with differentially signaled outcomes. In different conditions, either a fixed-ratio (FR) 1 or variable-interval (VI) 20-s schedule operated during initial links. We compared suboptimal choice across these conditions and evaluated it against a priori predictions derived from the SiGN model.

2. Method

2.1. Subjects and apparatus

The subjects were six adult *Columba livia* pigeons (age and sex unknown), numbered 161–166 and maintained at 85% ± 15 g of free-feeding bodyweight. Pigeons were housed in individual cages (375 mm high x 375 mm deep x 370 mm wide). Two perpendicular wooden perches were elevated above the cage floor. An operant panel was mounted on the right wall of the cage. The operant panel contained three circular 20-mm diameter plastic response keys spaced 100 mm apart. Pecks to the keys exceeding 0.1 N were recorded. A hopper, filled with wheat, was located behind a magazine aperture which sat 60 mm above the perches. When a reinforcer was delivered, the magazine aperture was lit, and the hopper was raised for 2 s providing access to wheat.

2.2. Procedure

A concurrent-chains schedule was arranged (Fig. 1, right panel). During the initial link, the side keys were illuminated white. One key led to a suboptimal alternative with a reinforcer probability of.5 and the other key led to an optimal alternative with a reinforcer probability of.75. Terminal-link entry was arranged according to an independently scheduled FR 1 schedule (Conditions 1, 3, 4, and 6) or VI 20-s schedule (Conditions 2, and 5). After the initial-link schedule arranged entry, a peck to one side key started the terminal link, which lasted for 10 s and ended with or without a reinforcer delivery. If the suboptimal alternative was chosen, a reinforcer was arranged with a probability of.5, and the side key was lit one color (e.g., orange) if a reinforcer was available and a different color (e.g., red) if no reinforcer was available. If the optimal alternative was chosen, a reinforcer was arranged with a probability of.75, and the side key was lit one of two colors (e.g., green or yellow, chosen randomly; $p = .5$). Conditions 4, 5, and 6 were reversal conditions, in which the spatial locations and key colors associated with the optimal and suboptimal alternatives were reversed relative to earlier conditions. Key colors and locations were counterbalanced across pigeons and conditions (see Supplementary Materials).

Each session lasted for 96 trials or 1 h, whichever occurred first. In each session, 32 trials were free-choice trials, in which both initial-link keys were illuminated as described above. The remaining 64 trials were forced-choice trials, in which only one initial-link key was illuminated (split evenly between the suboptimal and optimal alternatives). Conditions lasted for 30 sessions each.

3. Results

3.1. Suboptimal choice

Visual inspection indicated that choice was stable by the last 10 sessions of each condition, so we used these sessions for all analyses. We paired conditions arranging the same contingencies but different key locations together for choice analyses; Conditions 1 and 4 (both FR 1), 2 and 5 (both VI 20 s), and 3 and 6 (both FR 1) were paired together. Fig. 2A shows percentage choice of the suboptimal alternative for each condition. In general, choice of the suboptimal alternative tended to be higher with the FR 1 initial-link schedule. However, there were differences in the strength of preference for the suboptimal alternative between replication conditions, and inspection of the individual-pigeon data indicated that this was because the pigeons tended to be biased towards one side key (e.g., the left key). Thus, to assess preference for the suboptimal alternative independent of bias, we calculated a bias-free choice measure for each pair (Davison and Nevin, 1999):

$$\textit{Suboptimal preference index} = 0.5 \quad \log\left(\frac{B_{subopt\ |\ subopt\ on\ left|}}{B_{opt\ |\ subopt\ on\ left|}} \bullet \frac{B_{subopt\ |\ subopt\ on\ right|}}{B_{opt\ |\ subopt\ on\ right|}}\right) \tag{1}$$

where $B_{X\ |\ subopt\ on\ Y}$ represents the number of responses to alternative X

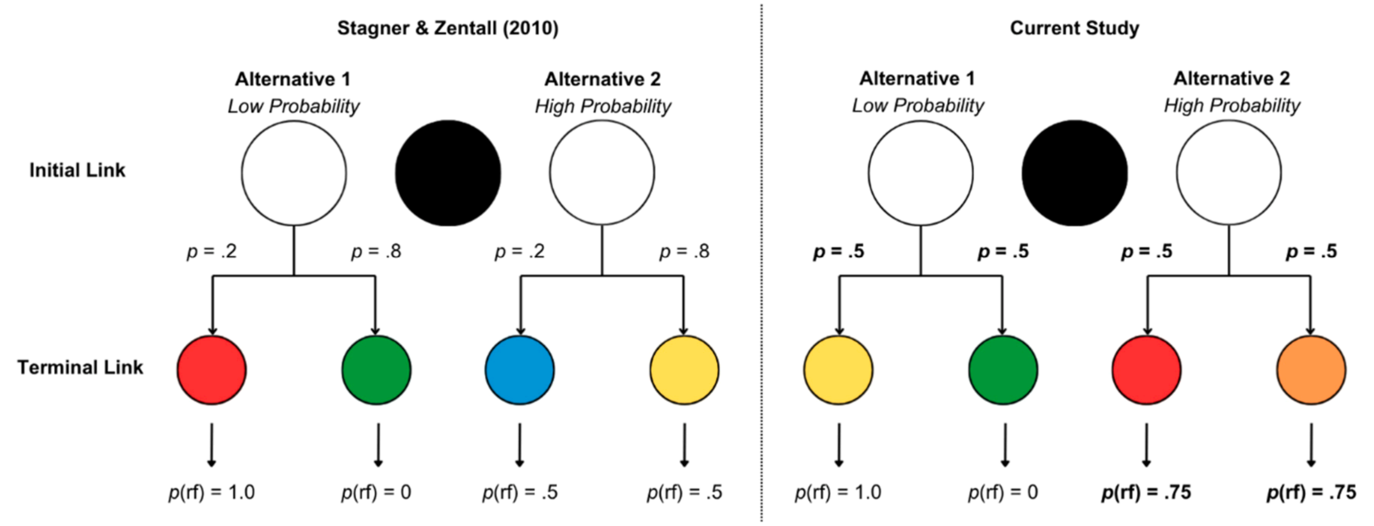

Fig. 1. *Comparison of Suboptimal Choice Procedure by* Stagner and Zentall (2010) *and the Current Study. Note.* The left panel shows Stagner and Zentall's (2010) procedure, in which the suboptimal alternative led to a reinforcer with a probability of.2 (signaled by a red key) and to no reinforcer with a probability of.8 (signaled by a green key). Equal.5 reinforcer probabilities were arranged on the optimal alternative, but reinforcer availability was nondifferentially signaled by blue and yellow keys. The right panel shows the current study's procedure, which systematically replicated Gipson et al. (2009) using reinforcer probabilities of.5 for the suboptimal alternative and.75 for the optimal alternative.

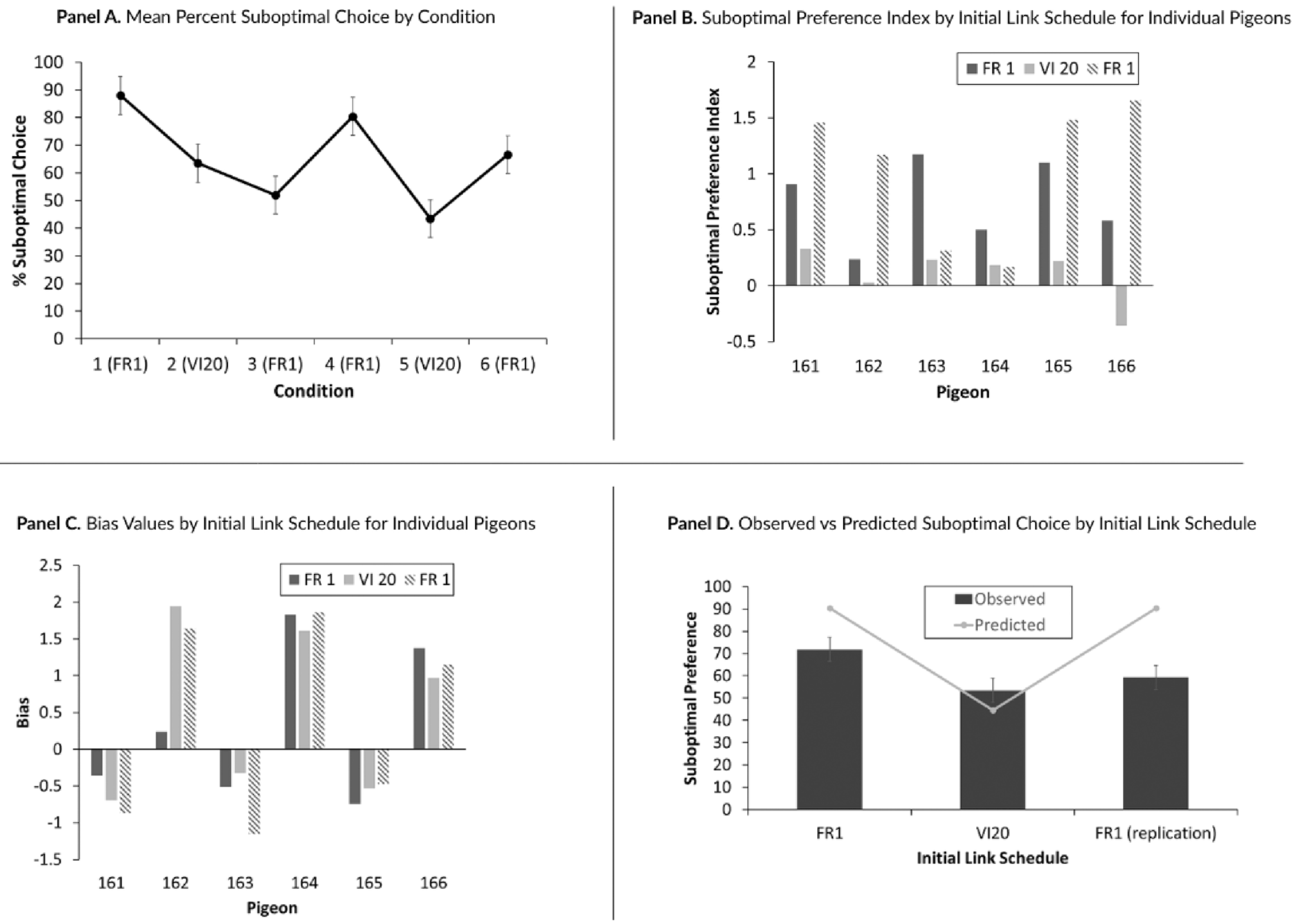

Fig. 2. *Suboptimal Choice (A), Suboptimal Preference Index (B), Bias (C), and Observed vs Predicted Choice (D). Note*. Panel A: Mean percent suboptimal choice across pigeons for each condition. Panel B: Suboptimal preference index for each initial link schedule. Panel C: Bias values for each initial link schedule. Panel D: Suboptimal choice as predicted by the SiGN model compared with observed choice. Standard error bars are included in Panels A and D for observed choice.

(suboptimal, subopt, or optimal, opt) when the suboptimal alternative was on key Y (left or right). Positive values reflect preference for the suboptimal alternative, and negative values reflect preference for the optimal alternative. A value of zero indicates indifference.

Fig. 2B shows preference during initial links for individual pigeons. Overall, subjects preferred the suboptimal alternative, and such preference was stronger with a FR 1 initial-link schedule. This was corroborated by a one-way repeated-measures ANOVA which showed a significant main effect of initial-link schedule, $F(2, 10) = 6.52, p = .015$, $\eta^2_p = .57$. Pairwise comparisons (Bonferroni-adjusted) revealed that suboptimal preference was stronger in the first FR 1 condition, compared to the VI 20-s condition ($p = .014$). However, no significant difference was found between the second FR 1 condition and the VI 20-s condition ($p = .094$), or between the FR 1 conditions ($p = 1.00$).

3.2. Bias

We also calculated a measure quantifying bias towards one key location:

$$Bias = 0.5 \quad \log\left(\frac{B_{right\ |\ subopt\ on\ left|}}{B_{left\ |\ subopt\ on\ left|}} \bullet \frac{B_{right\ |\ subopt\ on\ right|}}{B_{left\ |\ subopt\ on\ right|}}\right) \tag{2}$$

where the parameters are as in Eq. 1, except that responses to the left and right keys are used. Positive values indicate a stronger bias towards the right key (regardless of whether that key was the suboptimal or optimal alternative) and negative values indicate a stronger bias towards the left key. Fig. 2C shows that Pigeons 161, 163, and 165 were biased towards the left key, whereas Pigeons 162, 164, and 166 were biased towards the right key. Thus, initial-link preference depended on the initial-link schedule, trial outcomes (Fig. 2B), and bias towards one key location regardless of its outcome (Fig. 2C).

3.3. SiGN model

The SiGN model predictions were calculated as per Dunn et al. (2024); see Supplementary Materials). The model predicted that the percentage of suboptimal responses would be 90.25% in the FR 1 condition, and 44.60% in the VI 20-s condition. Fig. 2D compares predicted values with the obtained percentage of suboptimal responses in FR 1 conditions, and predicted values with suboptimal responses in the VI 20-s conditions. Predicted and obtained values were similar in FR 1 conditions, and paired-samples *t*-tests indicated no significant differences in Conditions 1 ($t(5) = -.42, p = .695, d = -.17$, 95% CI [-.97,.65]), 3 ($t(5) = -.70$, $p = .515$, $d = -.29$ [95% CI –1.09,.55]), 4 ($t(5) = -1.88$, $p = .119$, $d = -.77$ [95% CI –1.67,.18]), and 6 ($t(5) = -1.37$, $p = .230$, $d = -.56$ [95% CI –1.40,.33]). In the VI 20-s conditions, predicted suboptimal choice was lower than obtained choice in Condition 2, though this difference was not significant ($t(5) = 1.40$, $p = .222$, $d = .57$ [95% CI −.32, 1.42]). There was little difference between predicted and obtained values in Condition 5 ($t(5) = -.07$, $p = .951$, $d = -.03$ [95% CI −.83,.76]). Thus, despite deviations in obtained and predicted suboptimal choice in some conditions, such deviations did not reach statistical significance.

3.4. Discrimination

To assess whether discriminability varied across conditions, a discrimination index was calculated for the suboptimal alternative, defined as the proportion of responses emitted during the stimulus signaling reinforcement availability relative to total responding. Discrimination indices showed high discrimination between stimuli signaling reinforcement availability and non-availability across all conditions ($M = .97$). Furthermore, discrimination did not vary systematically between conditions, or as a function of initial-link schedule; discrimination indices for VI 20-s conditions ($M = .97$) were comparable to those for FR 1 conditions ($M = .97$).

4. Discussion

We found that suboptimal choice depended on the initial-link schedule; suboptimal preference was weaker with a VI 20-s initial-link schedule than an FR 1 schedule. This replicates previous research showing that longer initial-link durations shift preference towards the optimal alternative, even when discriminative stimuli are available on the suboptimal alternative (McDevitt, Dunn, et al., 2016; McDevitt, Pisklak, et al., 2024). According to the SiGN model (McDevitt, Dunn, et al., 2016), this effect of initial-link duration can be explained in terms of primary- and conditioned-reinforcer effects. As the initial-link duration increases, terminal-link stimuli on either alternative signal a reduction in reinforcer delay; hence, conditioned-reinforcer effects on both alternatives are more similar, and primary reinforcer rates exert stronger control. Our findings add to the evidence showing that the SiGN model adequately predicts suboptimal choice (see Dunn et al., 2024, for a review).

Although the key location of the suboptimal alternative varied between conditions, this did not result in choice also reversing locations (Fig. 2A). Discrimination between terminal-link stimuli on the suboptimal alternative was high and consistent across all conditions, indicating reliable differentiation between stimuli signaling reinforcement availability and non-availability. Moreover, discrimination did not vary systematically as a function of initial-link schedule. Thus, the pigeons could discriminate the suboptimal and optimal terminal links. Instead, it appears that initial-link choice was strongly modulated by idiosyncratic key-location biases. The source of such biases is unclear; the pigeons' prior experience appeared not to contribute because there was no systematic relationship between the contingencies in their previous (unpublished) experiment and bias in the current experiment.

Thus, the present findings show that biases can modulate suboptimal choice: Preference for the suboptimal alternative may be stronger when that alternative is consistent with bias, and weaker when that alternative is inconsistent with bias (see Fig. 2A). Bias effects are expected to be more pronounced when other determinants of choice between alternatives exert weaker control (Davison and McCarthy, 1988). Therefore, in this study, bias appeared to exert substantial control over choice. Idiosyncratic key-location biases may also explain why deviations between obtained choice and choice predicted by the SiGN model were apparent, particularly in Condition 2, which arranged VI 20-s in the initial link (Fig. 2D). Such deviations likely reflect key-location biases, which are not considered in the SiGN model.

Despite strong key-location biases, the bias-free measure of preference still indicated greater suboptimal choice in conditions with the shorter initial link (Fig. 2). Our findings thus demonstrate that suboptimal choice depends on the initial-link schedule, trial outcomes, and idiosyncratic biases that modulate preference. Although the impact of bias on suboptimal choice may be reduced by using non-spatial suboptimal and optimal alternatives (e.g., different colors, with their locations counterbalanced across trials), some research suggests that location may exert control even when it is irrelevant (e.g., Iversen, 1997; Urcuioli, 2008). As such, it may be worthwhile for future work to consider how location biases impact on suboptimal choice.

When the FR 1 condition was reintroduced after the VI 20-s condition, preference for the suboptimal alternative was more extreme than the first FR 1 condition for 4/6 pigeons (Fig. 2B). This may reflect carryover from the prior VI 20-s condition; perhaps the contrast between the initial link schedules strengthened the effects of terminal-link stimuli (e.g., they 'appeared' to be more reliable signals relative to the previous condition), resulting in stronger preference for the suboptimal alternative.

In summary, the present findings add to the evidence showing that pigeons prefer an alternative producing discriminative stimuli correlated with reinforcer availability over an alternative without such differential signals, even if the former arranges a lower overall reinforcer rate. We also show that such suboptimal choice is modulated by initial-link duration, and key-location biases. Thus, our findings suggest that conditioned- and primary-reinforcer effects alone do not describe suboptimal choice; future work should also consider the role of procedural factors, such as spatial versus non-spatial alternatives or carryover between conditions.

CRediT authorship contribution statement

Douglas Elliffe: Writing – review & editing, Project administration, Methodology, Data curation, Conceptualization. **Tess Austin:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Stephanie Gomes-Ng:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Bai John Y. H. Bai:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Sarah Cowie:** Writing – review & editing, Formal analysis, Data curation.

Author note

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.beproc.2026.105380.

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