Supporting Information

Pompilio and Kacelnik 10.1073/pnas.0907250107

Data Analysis

Proportions of choices were arcsine square root transformed and inspected for normality and homogeneity of variance (Jarque-Bera test of normality and Bartlett's test of the hypothesis that error variance of the dependent variable is equal across the different treatments) (1). The assumptions necessary for parametric analyses were never violated by the transformed data ($P >$ 0.05 in both cases).

Results

Our detection of the effect of context in Experiment 2 may suffer from a conservative bias: We may have underestimated the effect of ranking because the birds had experienced during Pre-Training some choices between $B_{(10s)}$ and $C_{(14s)}$, strongly favoring $B_{(10s)}$. A carryover from this phase could have pulled down the attractiveness of $C_{(14s)}$. For this reason we cannot fully discard the possibility that in the absence of this preexposure, the effect of ranking would have shown more extreme priority over immediacy, perhaps with a positive preference for $C_{(14s)}$ over $B_{(10s)}$.

In Experiment 1 we investigated possible differences in preferences between: (*i*) choice trials presented either at the end of a context presentation or after another choice trial ("choice-trial order"), (*ii*) subjects that experienced different order between Test 1 and Test 2 during the Choice phase ($A_{(5s)}$ vs. $C_{(10s)}$ from day 1–6 and $B_{(10s)}$ vs. $C_{(10s)}$ from day 7–12, and vice versa; meaning "phase order"). As mentioned before, half of the subjects were initially confronted with choices of $C_{(10s)}$ vs. $B_{(10s)}$ and the other half with choices of $A_{(5s)}$ vs.$C_{10s)}$, with choices being reversed in the second week of the choice stage. As dependent variables we considered, for each analysis, the proportion of choices for $C_{(10s)}$ vs. $B_{(10s)}$ (Test 1) and the proportion of choices for $A_{(5s)}$ vs. $C_{(10s)}$ (Test 2). For both Test 1 and Test 2, the results were similar. There were no significant effects of choice-trial order ($F_{1.5} = 0.01$, $P =$ 0.94 for Test 1 and $F_{1.5} = 0.02$, $P = 0.89$ for Test 2). There were no significant effects of phase order ($F_{1.5} = 0.02$, $P = 0.9$ for Test 1 and $F_{1.5} = 1.36$, $P = 0.31$ for Test 2). The interaction between choice-trial order and phase order was also not significant for either comparison ($F_{1.5} = 2.21$, $P = 0.21$ for Test 1 and $F_{1.5} = 0.15$, $P =$ 0.72, for Test 2). In Experiment 2 we compared the proportion of choices for $C_{(14s)}$ between choice trials presented either after the end of a context presentation or after another choice trial. The result of a matched-pairs *t* test shows no significant differences between them ($t_{(1.5)} = 1.91$, $P = 0.12$).

Although our focus is on the effect of past (remembered) context, it is conceivable that the context in which a given choice is embedded might have an effect as well. We compared, for each test, choices presented at the end of a Context AB presentation against those at the end of a Context CD presentation. A matched-pairs *t* test showed no significant differences in the proportion of choices between them [$t_{(1.5)} = t = -0.99$, $P = 0.37$ for option $C_{(10s)}$, (Test 1, Experiment 1); $t_{(1.5)} = 1.58$, $P = 0.17$ for option $A_{(5s)}$ (Test 2, Experiment 1); $t_{(1.5)} = 0.26$, $P = 0.80$ for option $C_{(14s)}$ (Test 3, Experiment 2)]. Notably, previous work in which utility was manipulated through need also found significant effects of the context of learning but not of the state during testing (2).

In Experiment 1 we analyzed whether the levels of preference between $C_{(10s)}$ and $B_{(10s)}$ (Test 1) and between $A_{(5s)}$ and $C_{(10s)}$ (Test 2) were stable along the Choice phase. In both cases, the slope of a linear regression of proportion of choices against session number was not significantly different from 0 (slope = 0.51, $t_{(1.5)} = 1.17$, $P = 0.3$ and slope = −0.44, $t_{(1.5)} = -0.99$, $P =$ 0.38 for Test 1 and Test 2, respectively), meaning that preference levels did not significantly increase or decrease along the choice sessions. Similarly, in Experiment 2 we analyzed the mean proportion of choices for option $C_{(14s)}$ vs. $B_{(10s)}$ (Test 3) across time (from day 1 to day 6 of the Choice phase). The slope of a linear regression was calculated to analyze whether preferences were stable across testing. The slope was not significantly different from 0 (slope = 0.08, $t_{(1.5)} = 0.17$, $P = 0.87$), meaning that there was no significant tendency for preferences either to increase or decrease along these days.

To test whether the increase in preference for C over B was mediated through timing distortions rather than motivational processes, we examined both the location of peaks and the between-trials pecking rate in probe trials in both conditions. The meaning of these analyses is sensitive to assumptions about the underlying pecking pattern in individual trials. For instance, a smooth average pecking rate function such as that in Fig. 3 could result if individual trials also show such a smooth variation in rate or if in each trial there is a switch between a low and a high response rate in the neighborhood of the subjective time of reinforcement. If the latter were the case, the pecking rate result shown in the figure would be a function of the distribution across trials of the onset and offset of the high response rate, rather than representing the existence of within trial peaks (3). It is debatable whether mean pecking rate or an analysis of peak distribution is more informative to whether timing mediated the observed choice effects, so we conducted both.

To conduct the peak location analysis, we first determined the 1-s time bin in which pecking rate was each trial's maximum. In trials with multiple bins sharing the maximum pecking rate we assigned the peak to the median bin. For example, if in a given trial the maximum pecking rate was shown in the 4th, 9th, and 11th time bin, we assigned the peak in that trial to bin 9. We then computed the across-trial mean peak location for each bird and option, and conducted our timing analysis on these data. Across birds, mean (±SD) peaks occurred at 14.72 s for option B and 13.90 s for option C. The fact that these peak locations do not coincide with the peak in average pecking pattern at 10 s (Fig. 3 and Fig. S1) is a reflection of the difference between the analyses. A matched-pairs *t* test found the effect of option on peak location to be nonsignificant ($t_{(1.5)} = 1.29$, $P = 0.25$).

To test if a timing effect could be detected through mean pecking rates we performed a repeated-measure ANOVA having pecking rate as function of Option (B, C) and of Time Bin (from 1 to 30). In such an analysis the possibility of a timing effect depends on the interaction between bin and option. A significant effect of bin indicates that pecking is nonrandom respect to time into the interval, an effect of option indicates that the level of pecking differed between options (as expected from motivational changes) and a significant interaction indicates that the shape of the functions differs and thus there is a timing effect. There were significant effects of Option $F_{2.5} = 11.62$, $P = 0.02$ and Time Bin $F_{2.5} = 69.12$, $P < 0.001$ but no significant interaction between them $F_{2.5} = 0.96$, $P = 0.52$. This result implies that the level of pecking rate was reliably higher for option $C_{(10)}$ than for $B_{(10)}$ but that there is no evidence of a timing effect. To confirm this visually, Fig. S1 presents relative pecking rate. Pecking rates for each option in this figure are represented as a proportion of the rate exhibited at the peak time (the results were first calculated by bird and then averaged). There is a near perfect superposition of the relative pecking pattern. It is thus extremely implausible that the preference for $C_{(10)}$ over $B_{(10)}$ in Test 1 could have been mediated by distortions in temporal memory.

1. Zar JM (1999) *Biostatistical Analysis* (Prentice Hall, Englewood Cliffs, New Jersey), 4th Ed.
2. Pompilio L, Kacelnik A (2005) State-dependent learning and suboptimal choice: When starlings prefer long over short delays to food. *Anim Behav* 70:571–578.
3. Gibbon J, Church RM (1990) Representation of time. *Cognition* 37:23–54.

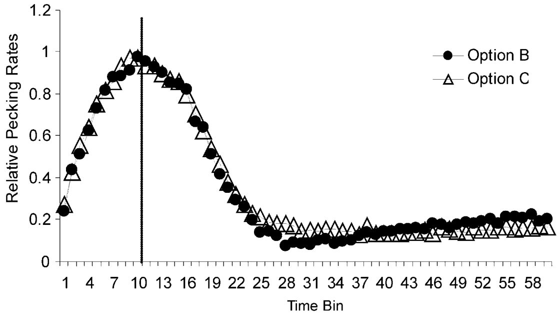

Fig. S1. Average of the relative pecking rates for options $B_{(10s)}$ and $C_{(10s)}$ for each 1-sec time bin. The graph was obtained by calculating relative pecks rates as a proportion of the rate exhibited at the peak time. The temporal axis was not standardized.

Table S1. Example of a sequence of sessions and trial presentations during the Training and Choice phases

Sessions	Sequence of events
First session	*Choice trial 1*
	Choice trial 2
	Context AB: A-B-A-A-B. . .*
	Choice trial 3
	Choice trial 4
	5 min. break
	Context CD: C-C-D-C-D. . .*
	Choice trial 5
	Choice trial 6
	20 min. break
Second session	*Choice trial 7*
	Choice trial 8
	Context AB: B-A-A-B-B. . .*
	Choice trial 9
	Choice trial 10
	5 min. break
	Context CD: C-C-D-D-D. . .*
	Choice trial 11
	Choice trial 12
	20 min. break
Third session	*Choice trial 13*
	Choice trial 14
	Context AB: A-B-A-A-B. . .*
	Choice trial 15
	Choice trial 16
	5 min. break
	Context CD: C-D-C-D-D. . .*
	Choice trial 17
	Choice trial 18
	5 hours of food ad libitum

Choice trials are shown in italics because they occurred exclusively during the Choice phase.

Half of the subjects started session 1 with context AB, as in this example, and the other half started the sequence with context CD.

*A total of 20 single-option trials (10 presentations of each option).