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Prospective control by reinforcers in human choice: Misallocation and bias, but not time orientation, influences reinforcer control

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ABSTRACT

Research with nonhuman animals and children suggests reinforcer control is *prospective*; that is, behaviour is organised according to the likely future, as extrapolated from past experience. The present experiment extended this work to adult choice, and also explored the effects of individual differences in past, present, and future time-orientation on reinforcer control. Participants ($N = 163$) responded in a concurrent schedule in which the probability of a reinforcer at the same location as the previous reinforcer varied across conditions. Choice tracked these probabilities, albeit imperfectly, indicating that reinforcers controlled behaviour prospectively. Deviations in choice from reinforcer probabilities were well-captured by a quantitative model assuming that such deviations arise because reinforcers are *misallocated* to the wrong alternative and because of *biases* towards one alternative. This replicates previous findings in pigeons and children, hence demonstrating the cross-species generality and developmental continuity of prospective reinforcer control. Individual differences in time orientation appeared not to influence reinforcer control, although further work is needed to explore the conditions under which time orientation modulates prospective reinforcer control.

1. Introduction

The *law of effect* (Thorndike, 1911) asserts that behaviours followed by pleasant consequences (*reinforcers*) will increase in frequency, whereas behaviours followed by unpleasant consequences (*punishers*) decrease in frequency. Such consequence control has traditionally been thought to reflect changes in the strength of behaviour, in the sense that reinforcers *strengthen* and punishers *weaken* past behaviour (Skinner, 1938; Thorndike, 1911). However, growing evidence questions this retrospective strengthening account, suggesting instead that behaviour is organised according to the likely *future* as extrapolated from past experience. Thus, reinforcers increase the behaviours they follow to the extent that those behaviours continue to produce reinforcers in the future (Cowie, 2018; Cowie and Davison, 2016, 2020; Shahan, 2017). In support of such prospective control, preference for repeating a just-reinforced behaviour decreases as the probability of obtaining another reinforcer for repeating that behaviour decreases (Bensemann et al., 2015; Krägeloh et al., 2005; Cowie et al., 2011, 2017, 2021).

Consequence control depends on discriminating relations between stimuli, behaviours, and consequences (Davison and Nevin, 1999). Choice is less sensitive to changes in reinforcer availability when the various stimuli or behaviours producing reinforcers are less disparate (e.g., Alsop and Davison, 1991; Davison and McCarthy, 1994; Godfrey and Davison, 1999; Miller et al., 1980). Even when stimuli or behaviours are relatively discriminable, choice still deviates from reinforcer ratios (Baum, 1974; Davison and Jenkins, 1985; Davison and Jones, 1995, 1998; Davison and Nevin, 1999). Thus, contingency discrimination is imperfect. Discrimination errors may arise because of memory or perceptual failures (e.g., forgetting which stimulus or behaviour produced a reinforcer), resulting in *misallocation* of consequences to the wrong stimulus or behaviour. Such misallocation weakens differential control by consequences, resulting in a mismatch between behaviour and arranged or obtained contingencies (Cowie and Davison, 2022; Davison and Cowie, 2022; Davison and Jenkins, 1985; Davison and Nevin, 1999). Because future events are extrapolated from the discriminated past, the effects of misallocation endure even with extended experience.

Individual differences also influence consequence control (e.g., Alsop et al., 2016; Kollins et al., 1997; Mukherjee et al., 2020; Ostaszewski, 1996; Slaney et al., 2022). For example, people who are more

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future oriented (strongly focused on future gains or losses) are better at delaying gratification across longer timescales (Daugherty and Brase, 2010; Kim et al., 2020; Rolison et al., 2017) and less likely to engage in risky behaviour (Diaconu-Gherasim et al., 2023; Keough et al., 1999; Măirean and Diaconu-Gherasim, 2023; Sekścińska et al., 2018; Zimbardo et al., 1997). This suggests that future-oriented individuals are more sensitive to potential future consequences; as a result, prospective consequence control may be stronger in such individuals. In comparison, retrospective control may be stronger in past-oriented individuals. That is, individual differences in prospective and retrospective reinforcer control may reflect differences in *time orientation* (the extent to which one is past-, present-, or future-oriented; Zimbardo and Boyd, 1999).

Existing research has primarily used animal models to investigate prospective control (see Cowie and Davison, 2016, for a review). Findings have recently been extended to children (Cowie et al., 2021; Wood and Simon, 2023), but not adults. Furthermore, prior studies have not explored the role of individual differences in prospective consequence control. The present experiment filled these gaps. Adults responded in a concurrent schedule in which the likely next-reinforcer location varied between conditions. We measured the extent to which choice was controlled by the next-reinforcer location, and the relationship between such reinforcer control and scores on a time-orientation measure (Zimbardo and Boyd, 1999). Additionally, to examine the contribution of reinforcer misallocation, we fit a model that redistributes reinforcers across alternatives to choice data (Cowie et al., 2021). This model successfully describes pigeons' (Cowie et al., 2016; Cowie and Davison, 2020; Davison and Cowie, 2022) and children's (Cowie et al., 2021) choice; hence, we tested its generalizability to adults' choice.

2. Method

2.1. Participants and procedure

Participants ($N = 163$) aged 18 and over completed one session on Psytoolkit (Stoet, 2010, 2017). The experiment ran online, and participants completed their session on their own personal computer in their own time. Participants received course credit or were entered into a prize draw after participating.

Participants were informed that they would play a game in which they would make choices, and their goal was to earn as many points as possible. They were given no further instructions; this meant that participants had to learn from experience about the reinforcement contingencies arranged in the game. In the game (Fig. 1A), each trial began with the presentation of two doors, one of which concealed a reinforcer. Participants clicked on a door to open it; if they chose the correct door, it opened to reveal the reinforcer (a funny image plus 10 points), whereas if they chose incorrectly, the door opened to reveal an empty space. A tracker in the top-right corner kept track of participants' total points earned (in reality, the points had no value, they were simply arranged to make clear what participants' goal was).

Participants completed three conditions signalled by different coloured backgrounds. The first reinforcer location in each condition was chosen randomly ($p = .5$). Thereafter, the location of subsequent reinforcers depended on the previous-reinforcer location. In Condition 1 (purple background), the probability of a reinforcer at the *same* location as the previous reinforcer was .65 or .35 (counterbalanced across participants). We term this the *Slight Stay/Switch* condition, because staying or switching was slightly more likely to produce the next reinforcer. In Conditions 2 (blue background; *Stay* condition) and 3 (yellow background; *Switch* condition), this probability was .9 or .1, respectively. Conditions lasted for 100 trials or 15 min, whichever occurred first. All participants completed Condition 1 first, and the order of Conditions 2 and 3 was counterbalanced across participants.

Finally, participants completed the Zimbardo Time Perspective Inventory (ZTPI), a well-validated scale measuring individual differences in time orientation (Zimbardo and Boyd, 1999). Cronbach's alphas for ZTPI subscales ranged from .79 to .86, indicating good internal reliability.

2.2. Choice analyses

We calculated the proportion of responses to the last-reinforcer location (*stay* responses), and the proportion of reinforcers obtained for staying in each condition. To quantify retrospective and prospective reinforcer control, we used the following measures:

$$\textit{Past control} = 0.5\log\left(\frac{B_{Stay|Stay\ condition}}{B_{Switch|Stay\ condition}} \bullet \frac{B_{Stay|Switch\ condition}}{B_{Switch|Switch\ condition}}\right) \tag{1}$$

$$\textit{Future control} = 0.5\log\left(\frac{B_{Stay|Stay\ condition}}{B_{Switch|Stay\ condition}} \bullet \frac{B_{Switch|Switch\ condition}}{B_{Stay|Switch\ condition}}\right) \tag{2}$$

where $B_{x\,|\,y}$ represents the number of stay or switch (x) responses in *Stay* (Cond. 2) or *Switch* (Cond. 3) conditions (y). We only used data from these conditions because they arranged the most extreme probabilities, and because all participants completed these two conditions. Eq. (1) measures preference for the last-reinforcer location, with more positive values indicating stronger retrospective control. Likewise, more positive values of Eq. (2) reflect stronger prospective control.

Finally, we fit a misallocation model to choice data (Cowie et al., 2021; see also Davison and Jenkins, 1985):

$$\log\frac{B_{Stay}}{B_{Switch}} = \log\frac{R_{Stay} \bullet (1-m) + R_{Switch} \bullet m}{R_{Switch} \bullet (1-m) + R_{Stay} \bullet m} + \log c \tag{3}$$

where B_x and R_x represent responses and reinforcers, respectively, for staying or switching. The parameter m quantifies misallocation, and ranges from 0 (no misallocation) to 0.5 (maximal misallocation). Log c quantifies bias, and may be zero (unbiased), positive (stay bias) or negative (switch bias).

3. Results

Fig. 1B shows the mean proportion of stay responses across trials in each condition. Choice shifted towards the likely next-reinforcer location and stabilised halfway through each condition, indicating that participants' behaviour was sensitive to the contingencies. Subsequent analyses used data from the last half of conditions. Fig. 1C shows stable choice as a function of the proportion of obtained stay reinforcers. The proportion of stay responses approximated the proportion of stay reinforcers, and the slope of the best-fitting line ($M = 0.80$, $SEM = 0.01$) differed from zero, Bayesian[2] t-test: $\text{BF}_{10} = 1.06 \times 10^{103}$, error % $<$ .0001. Future control (Eq. (2)) was stronger than past control (Eq. (1); Fig. 1D), $\text{BF}_{10} = 6.98 \times 10^{38}$, error % $< .0001$, thus, there was extremely strong evidence that choice was controlled by the likely next-reinforcer location.

Prospective control was imperfect, as evidenced by differences between the proportions of stay responses and reinforcers (Fig. 1C). The misallocation model (Eq. (3)) described choice well, with over 85 % of variance accounted for (VAC) in data from 151 participants, and over 70 % for seven others.[3] Misallocation values ranged from 0.00 to 0.44 ($M = 0.07$, $SEM = 0.00$), and bias ranged from 0.00 to 0.27 ($M = 0.07$, $SEM = 0.01$). Hence, deviations in choice from reinforcer probabilities reflected reinforcer misallocation and bias to stay at the last-reinforcer

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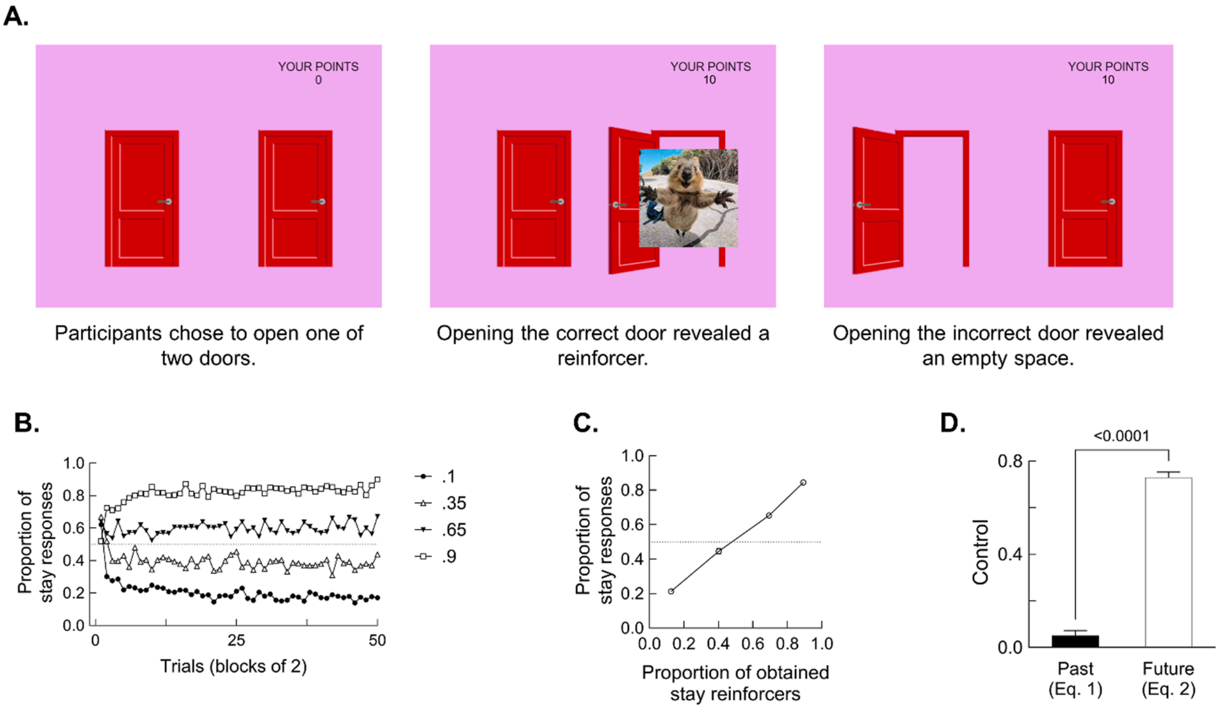
[2] Bayesian statistics are advantageous because they quantify the strength of the evidence in favour of the alternative hypothesis with a Bayes Factor (BF_{10}). BF_{10} values below 1 indicates anecdotal evidence, while larger values indicate stronger evidence in favour of the alternative hypothesis.

[3] The remaining six participants had VACs below 60 % ($N = 2$) or close to zero ($N = 4$). Due to the poor model fits, these participants' data were excluded from subsequent analyses involving the misallocation model.


Participants chose to open one of two doors.

Opening the correct door revealed a reinforcer.

Opening the incorrect door revealed an empty space.

Fig. 1. Example of events in a typical trial (A) and choice measures across participants (B to D). Note. (A) After participants clicked a door, it opened to reveal a reinforcer or an empty space. (B) Mean proportion of stay responses across blocks of two trials in each condition. (C) Mean proportion of stay responses as a function of the proportion of obtained stay reinforcers. (D) Mean past and future control (Eqs. (1) and (2)).

location.

Table 1 shows Bayesian correlational analyses between ZTPI subscale scores and choice measures. Correlation coefficients were close to zero, and BF_{10} values were less than 0.3. Thus, there was no evidence for a relationship between time orientation and reinforcer control.

4. Discussion

We investigated prospective reinforcer control in a choice procedure in which the likely next-reinforcer location varied across conditions. Participants' choice tracked the likely next-reinforcer location, albeit imperfectly (Fig. 1). Choice was well-described by a model suggesting that imperfect reinforcer control reflects reinforcer *misallocation* and *bias*. These results replicate findings in pigeons (Cowie et al., 2011, 2013, 2016; Gomes-Ng et al., 2018; Krägeloh et al., 2005) and children (Cowie et al., 2021; Wood and Simon, 2023), and hence add to the evidence demonstrating that reinforcers control behaviour primarily by virtue of the information they provide about the likely future.

Our participants' stay bias may suggest that reinforcers also exerted a small strengthening effect on past behaviour. Alternatively, such bias may reflect differences in the physical effort associated with staying at the just-reinforced alternative versus switching to the not-just-reinforced alternative. Here, the mouse cursor remained at the most recently chosen location after a response (unless participants moved it themselves); this may have increased the likelihood of a stay response because this required less effort than switching (see e.g., Baum, 1982; Boutros et al., 2011; Cheney et al., 1985; Gomes-Ng et al., 2022). To test this, future research could require participants to return the cursor to the centre of the screen between trials. If this weakens the stay bias, then our participants' bias was probably related to a procedural artefact rather than a reinforcement-strengthening effect.

In contrast to our participants, children in Cowie et al. (2021) were biased to *switch* alternatives. Although our participants' stay bias may be partly artefactual, the difference between adults and children may also suggest a developmental change, as children are more likely to explore alternatives – consistent with a bias to switch – than adults (e.g., Schulz et al., 2019). Another difference between our adults and Cowie et al.'s children is that misallocation values were lower in the present study. This may reflect a decrease in discrimination errors with age (e.g., Smeets and Barnes, 1997), as well as different reinforcer durations: Cowie et al.'s children interacted with reinforcers for 15 s, which may have made it harder to remember the last-reinforcer location compared with our experiment in which reinforcers required no interaction and lasted 1.2 s. Thus, developmental and procedural differences likely contributed to differences between our and Cowie et al.'s findings.

Interestingly, we found no relationship between time orientation and reinforcer control (Table 1); retrospective control was not necessarily stronger in past-oriented individuals, nor was prospective control stronger in future-oriented individuals. This is somewhat surprising, as other studies have found differences in preference for delayed

Table 1
Coefficients for correlations between ZTPI subscales and choice measures.

	Past Negative	Past Positive	Present Hedonistic	Present Fatalistic	Future
M (*SD*)	3.39 (0.77)	3.28 (0.68)	3.35 (0.55)	2.86 (0.72)	3.45 (0.57)
Past control	−0.05	0.01	0.07	0.02	−0.08
Future control	0.05	−0.09	−0.07	−0.04	0.06
Misallocation (*m*)	−0.04	0.04	0.11	−0.09	−0.01
Bias (log *c*)	−0.02	−0.03	0.01	−0.09	−0.02

Note. All BF_{10} values were between 0.1 and 0.3, indicating moderate evidence for the null hypothesis of no correlation.

reinforcers based on time orientation (Daugherty and Brase, 2010; Kim et al., 2020; Rolison et al., 2017). One possibility is that such differences may only be apparent when reinforcers are *delayed*. Alternatively, ceiling effects may have masked the relationship between time orientation and reinforcer control here. Our participants discriminated reinforcer probabilities well, hence, there was only a small amount of variability in reinforcer control (Fig. 1D). Given that correlation strength is positively related to variability (e.g., Goodwin and Leech, 2006), our results may reflect a lack of variability rather than the true absence of a relationship between time orientation and reinforcer control. Future studies could make the choice task harder to reduce the potential impact of ceiling effects (e.g., varying the discriminability of the choice alternatives).

One important difference between human and non-human animal studies of prospective reinforcer control is the type of reinforcer schedule. Human studies arrange fixed-ratio (FR) schedules, in which every response is followed by a consequence (the presence or absence of a reinforcer, as in the present study and in Cowie et al., 2021). In contrast, studies with non-human animals arrange variable-interval (VI) schedules (e.g., Cowie et al., 2011). Under such intermittent reinforcer schedules, subjects can make multiple responses to either alternative during inter-reinforcer intervals (IRIs), and reinforcer control depends on subjects' ability to *remember* the previous reinforcer location throughout the IRI. This likely makes the contingencies more difficult to discriminate compared with FR 1 schedules, in which reinforcers are delivered immediately following a single response (i.e., there is no IRI, besides the time taken to emit the next response). Thus, future studies with humans could arrange intermittent, rather than continuous, schedules. This may help to eliminate ceiling effects, and would also serve as a useful test of how reinforcers control humans' behaviour prospectively in more uncertain or unpredictable environments.

Finally, could a retrospective, strengthening account of reinforcers account for the present findings – and those in previous studies of reinforcer control (e.g., Bensemann et al., 2015; Krägeloh et al., 2005; Cowie et al., 2011, 2017, 2021) – if the operant were defined in terms of 'staying' or 'switching', rather than a 'left' or 'right' response? Under such a redefinition, we could describe reinforcers as strengthening the choice to stay at the same alternative, or the choice to switch to the other alternative. However, this line of reasoning implies that reinforcers strengthened different behaviours in different conditions, even though the reinforcers obtained and responses emitted were identical across those conditions. Thus, reframing the operant means that reinforcers strengthened staying when staying was more likely to produce more reinforcers, and they strengthened switching when switching produced more reinforcers – a circular explanation (reinforcers strengthened staying/switching because staying/switching produced more reinforcers). Furthermore, redefining the operant post-hoc produces an unfalsifiable theory, because it will always be possible to redefine the operant to be consistent with a retrospective account (see Cowie, 2020; Simon et al., 2020 for further discussion). Thus, we believe that the most parsimonious interpretation of our findings (and those of past research) is a prospective account.

In conclusion, our findings add to evidence demonstrating behaviour is controlled by the likely future as extrapolated from past experience, to the extent that subjects can discriminate contingencies. Mismatches between behaviour and contingencies arise from reinforcer misallocation coupled with biases. Individual differences in time orientation appear not to influence reinforcer control, but further work is needed exploring the conditions under which this is (or is not) true. Our findings extend previous research with pigeons and children to adults, providing insight into cross-species similarity, and potential developmental differences, in how reinforcers control behaviour.

CRediT authorship contribution statement

Stephanie Gomes-Ng: Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Kaung Thant Maung:** Writing – review & editing, Investigation. **Sarah Cowie:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Data availability

Data will be made available on request.

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