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journal homepage: www.elsevier.com/locate/COGNITBiases in preferences for sequences of outcomes in monkeys[☆]Tommy C. Blanchard^{a,b,*}, Lauren S. Wolfe^a, Ivo Vlaev^{c,d}, Joel S. Winston^{e,f,g}, Benjamin Y. Hayden^{a,b}^a Department of Brain and Cognitive Sciences, University of Rochester, Meliora Hall, Rochester, NY 14627, United States^b Center for Visual Science, University of Rochester, Meliora Hall, Rochester, NY 14627, United States^c Centre for Health Policy, South Kensington Campus, London SW7 2AZ, United Kingdom^d Department of Surgery and Cancer Imperial College London, South Kensington Campus, London SW7 2AZ, United Kingdom^e UCL Institute of Cognitive Neuroscience, University College London, 12 Queen Square, London WC1N 3BG, United Kingdom^f Wellcome Trust Centre for Neuroimaging, University College London, 12 Queen Square, London WC1N 3BG, United Kingdom^g Department of Neurology, Northwestern University, 303 East Chicago Avenue, Ward 10-185, Chicago, IL 60611, United States

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ABSTRACT

Movies, vacations, and meals are all examples of events composed of a sequence of smaller events. How do we go from our evaluations of each scene in a movie to an evaluation of the sequence as a whole? In theory, we should simply average the values of the individual events. In practice, however, we are biased towards sequences where each element tends to be better than the previous, where the last value is large, and we overweight the best (or worst) part of the sequence. To study how general these biases are we examined monkeys' preferences for sequences of rewards in a novel *reward repeat* task. Monkeys were first given a sequence of rewards and then chose between repeating the sequence or receiving a standard comparator sequence. We found that, like humans, monkeys overweight events that happen later in a sequence, so much so that adding a small reward to the end of a sequence can paradoxically reduce its value. Monkeys were also biased towards sequences with large peak values (the highest value in the sequence), but only following a working memory challenge, suggesting that this preference may be driven by memory limitations. These results demonstrate the cross-species nature of biases in preferences for sequences of outcomes. In addition, monkeys' consistent preference for sequences in which large values occur later challenges the generality of discounting models of intertemporal choice in animals.

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1. Introduction

We must often evaluate experiences that occur over extended periods of time and involve a mix of reward intensities and valences (Loewenstein & Prelec, 1993). For

example, how much did we enjoy a specific two-hour movie, three-course meal, or seven-day vacation? And how much would we pay for another similar sequence? To make these evaluations, we must mentally combine the utilities of multiple individual moments into a single value. In theory we should just sum the experienced utilities of the constituent events – the order of events occur should not matter. How much we feel we have enjoyed a movie should just be a function of how much we enjoyed each scene individually. However, human and animal decision-makers typically discount rewards as an increasing function of delay (Rachlin, 2004). One would expect, then, that we would prefer sequences with the highest valued events

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* Corresponding author. Address: Department of Brain and Cognitive Sciences, University of Rochester, Meliora Hall, Rochester, NY 14618, United States. Tel.: +1 5857051807.

E-mail address: blanchard.tommy@gmail.com (T.C. Blanchard).

early (Frederick, Loewenstein, & O'Donoghue, 2002; Loewenstein & Prelec, 1993), meaning a movie with a strong start would be preferred to one with a strong ending.

Common sense dictates that the overall utility of an experience is the sum (or average) utility of its components. Discounting models predict that, because we prefer rewards sooner rather than later, we should invariably prefer declining sequences to improving ones that are matched for average value. Contrary to both of these, humans often prefer sequences to increase in value over time (Ariely, 1998; Chapman, 1996; Chapman, 2000; Frank & Hutchens, 1993; Hsee, Abelson, & Salovey, 1991; Hsee & Abelson, 1991; Loewenstein & Prelec, 1993; Loewenstein & Sicherman, 1991; Prelec & Loewenstein, 1991; Ross & Simonson, 1991). Closely related biases motivate us to value sequences in which the more positive events occurred near the end (the *end bias*), sequences with greater peak intensities regardless of when they occur (the *peak bias*), and sequences with increasing reward intensity (the *trend bias*) (Kahneman, Fredrickson, Schreiber, & Redelmeier, 1993; Loewenstein & Prelec, 1993; Redelmeier & Kahneman, 1996). That is, we would expect that people overweight the best scene and ending of a movie when reporting how much they enjoyed the film. Together, these biases are a defining feature of our intertemporal preferences. These preference patterns apply to positive and aversive domains, have been confirmed in field studies, and may be harnessed to improve health and welfare (Clark & Georgellis, 2004; Do, Rupert, & Wolford, 2008; Kahneman, 1999; Redelmeier & Kahneman, 1996; Redelmeier, Katz, & Kahneman, 2003). So robust are these effects that merely reframing rewards as being part of a sequence rather than independent events can cause a switch in preference from decreasing towards increasing sequences (Loewenstein & Prelec, 1993). Together, these results pose a major challenge to standard theories about temporal allocation of rewards and suggest that psychological factors can overwhelm discounting preferences in intertemporal choice (Frederick, Loewenstein, & O'Donoghue, 2002).

Understanding animal economic preferences provides an important point of comparison with human economic preferences (Real, 1991; Stevens & Stephens, 2010). Studies of animals economic preferences in the laboratory have provided a great deal of information about the cognitive processes they use to make decisions, giving us insight into the mental lives of animals (Brosnan & de Waal, 2003; Brosnan et al., 2007; Chen, Lakshminarayanan, & Santos, 2006; Egan, Bloom, & Santos, 2010). We know almost nothing about how animals evaluate sequences of rewards (but see Xu, Knight, & Kralik, 2011). The well-established steep discounting observed across taxa would predict that animals strongly prefer decreasing sequences to flat ones and flat ones to increasing ones.

We studied the preferences of three rhesus monkeys in a simple sequence preference task. Rhesus monkeys offer an ideal model organism for studying intertemporal preferences – their psychology is well studied, they are flexible learners that do not readily fall into behavioral stereotypes, and they have time preferences that are similar to those of other animals (Glimcher, Kable, & Louie, 2007;

Kim, Hwang, & Lee, 2008; Stevens, Rosati, Ross, & Hauser, 2005). On each trial of our novel *reward repeat* task, monkeys were given a sequence of five rewards and then offered a choice between repeating that sequence or obtaining a well-learned comparator sequence consisting of five repeats of a single value (either [2.2.2.2.2.2.2.2], [3.3.3.3.3], [3.4.3.4.3.4.3.4], or [4.4.4.4.4]). We then estimated a subjective value for each probe sequence by fitting a preference function.

We found that monkeys assign more decision weight to events later in the sequence. Indeed, the addition of a small reward at the end of a sequence can, paradoxically, reduce its value (cf. Kahneman et al., 1993; Schreiber & Kahneman, 2000). These results are reminiscent of those observed in humans and suggest that similar heuristics are employed by humans and monkeys in guiding choices over extended sequences. Unlike humans, monkeys did not prefer sequences with large peaks in the standard version of our task, although we induced a peak bias in monkeys by adding a weak working memory challenge (a four second delay preceding choice). Collectively, these results highlight the potential importance of memory in driving preferences and challenge discounting models of animal intertemporal preferences.

2. Methods

2.1. Behavioral task

Trials were randomly chosen from a larger set of possible sequences and interleaved. We collected about twice as much data from subject H as from subjects J and K. The amount of data collected was determined by subject and experimenter availability and was not in any way determined by examining data. No subjects were excluded from the study. Our computer monitor had a 1024 × 768 resolution and was placed 144.8 cm (57 in.) in front of the subjects.

Each trial of the task consisted of three steps:

Step 1, probe reward: The probe cue appeared (a photograph of some rocks, see Fig. 1). After 500 ms, a sequence of five fluid rewards was given, each separated from the next by 500 ms. The duration of the rewards ranged from 20 ms to 80 ms. The time required to give the reward did not slow down the delivery of the next reward. The identity of the rewards varied with task condition (see below). When the number zero appears in a sequence, this indicates no reward was given but a 500 ms delay still occurred. In the one four-step sequence [2.2.2.8], no delay was imposed at the end. In the **working memory challenge** variant of the task, a four-second delay was added at the end of the probe reward period and before the choice; the monitor was kept blank during this time. Note that, for ease of description, values are normalized to a standard value of 1 = 0.01 mL.

Step 2, choice: Following a 500 ms delay, two targets appeared, centered 16.5 degrees of visual angle to the left and right of the central spot. The **probe** stimulus consisted of the same neutral photographic stimulus that appeared in Step 1 (the picture of rocks). The **comparator** stimulus consisted of a solid colored vertically oriented rectangle

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