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# An Allais Paradox Without Mental Time Travel

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**ABSTRACT: The capacity to anticipate future experiences of regret has been hypothesized to explain otherwise irrational aspects of human decision-making, including the certainty effect (Kahneman and Tversky (1979) Econometrica 47:263–291) and the common ratio effect (Allais (1953) Econometrica 21:503–546). The anticipated regret hypothesis predicts that individuals incapable of episodically imagining their personal futures, as has been reported for people with extensive damage to medial temporal lobe structures and resulting deficits in episodic thought, should be immune to these effects. We report that K.C., who has extensive bilateral damage to his hippocampus and adjacent medial temporal lobe structures and nearly complete deficits in his ability to episodically imagine his personal future, nonetheless displays both the certainty and the common ratio effects. These results suggest that the episodic anticipation of future regret does not explain the general human tendency to display the certainty and common ratio effects.**


**KEY WORDS: emotions; episodic memory; reasoning; risk taking; decision-making**

## INTRODUCTION

People often imagine future events and experiences when they make decisions. Such episodic future construction is thought to be involved in practical decision-making (Johnson et al., 2007; Ernst et al., 2012), to facilitate flexible planning (Suddendorf and Corballis, 1997; Suddendorf and Busby, 2005; Schacter et al., 2007), and to permit both the anticipation of future goals and needs and the identification of obstacles (Addis et al., 2007). Episodic future imagining ("mental time travel" or episodic prospection) also has been hypothesized to combat the tendency to devalue delayed rewards (Boyer, 2008) and to enhance the capacity to form and maintain intentions to perform future actions (Atance and O'Neill, 2001). Indeed, some data suggest that individuals with deficits in episodic memory and future imagining also perform poorly on standard decision-making tasks such as the Iowa gambling task (Gutbrod et al., 2006; Gupta et al., 2009; Delazer et al., 2010).

Yet it is important to consider whether there are situations in which imagining the future is not functional but instead biases human decision-making toward irrational choices. Situations in which one has to choose between certain and probabilistic outcomes might be one such context. People regularly opt for a certain reward over a risky option that has a greater expected utility, a phenomenon that Kahneman and Tversky (1979) called the *certainty effect*. According to the anticipated regret hypothesis (Loomes and Sugden, 1982), people tend to prefer the certain option because they anticipate the feelings of regret that they would experience if they chose the risky option and it did not pay off. Loomes and Sugden's regret hypothesis predicts that people who do not anticipate feeling regret will not show the certainty effect. Instead, they will make choices that maximize expected utility. That is, when choosing between a certain reward and a risky reward with greater expected value, people who do not anticipate feeling regret should choose the risky option.

Loomes and Sugden (1982) argue that anticipated regret also explains the common ratio effect, first identified by Allais (1953), in which participants irrationally change their preferences among a set of options when the probability of a reward in each option is reduced by a common factor (i.e., when the probabilities are multiplied by the same ratio). From the perspective of normative economic theory, such behavior is paradoxical because it violates the substitution axiom, one of the fundamental principles of expected utility theory (Allais, 1953; MacCrimmon and Larsson, 1979). However, Loomes and Sugden showed mathematically that if one makes certain assumptions about anticipation of regret and/or rejoicing following an actual outcome, then expected utility theory can explain the certainty effect, the common ratio effect, and a number of other violations of expected utility theory (e.g., Bell, 1982; Laciana and Weber, 2008; Bourgeois-Gironde, 2010).

As presented by Kahneman and Tversky (1979), the common ratio effect is exemplified by the fact that when offered a choice between a 100% chance of winning \$3,000 and an 80% chance of winning \$4,000, most people choose the sure thing (as in the

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certainty effect), but when the probabilities are reduced by a common factor (e.g., a 25% chance of winning $3,000 vs. a 20% chance of winning $4,000), the majority now pick the riskier gamble (i.e., the one with the lower probability of winning). A reverse pattern (i.e., negative certainty and common ratio effect) is observed when the outcomes are losses rather than gains. Such "Allaisian" choices are inconsistent with expected utility because the relative ranking of expected utilities among a set of options stays the same when the probabilities of each the outcomes for each option are each multiplied by the same constant. Yet subjects' preferences regularly change rank order under such manipulations.

Loomes and Sugden (1982) explicitly present the anticipated regret hypothesis as a competitor to Kahneman and Tversky's prospect theory as the explanation for why humans often deviate from the norms of expected utility. Throughout their paper, Loomes and Sugden (1982; pp. 805, 807, 817) argue for their theory and against its rivals on the basis of (a) the fact that it predicts a wide range of phenomena (including both the certainty and common ratio effects), (b) its simplicity, and (c) the fact that it continues to treat individuals as rational despite what would appear to be violations of classical expected utility. As the subtitle of their paper ("An Alternative Theory of Rational Choice Under Uncertainty") indicates, their explicit aim is to supplement the axioms of classical decision theory with those of regret theory. They do so to accommodate Kahneman and Tversky's (1979) experimental demonstrations of Allaisian behavior within the framework of rational choice. At stake for them is the very foundation of classical economic theory, the assumption that *homo economicus* is a rational decision maker. Loomes and Sugden call upon the anticipation of regret and of rejoicing to turn apparently irrational decisions rational.

Indeed, Loomes and Sugden (1982) argue that a person who could not anticipate regret would show neither the certainty effect nor the violations of expected utility theory (including the common ratio effect) noted by Kahneman and Tversky (1979):

> Some individuals may experience no regret or rejoicing at all . . .: in these special cases of our theory, we would predict that the individual's behavior would conform with all the conventional axioms [of expected utility theory]. (Loomes and Sugden, 1982, p. 820)

Loomes and Sugden mention here only the experiencing of regret and rejoicing, not the anticipation of regret and rejoicing. In the mechanics of their theory, however, it is the *anticipation* of future regret and rejoicing that influences the preference rankings. One who could not anticipate future states of regret and rejoicing would make decisions that conform to the axioms of expected utility theory.

The current study tests this prediction of regret theory. In doing so, the study examines whether the episodic systems proposed to be centrally involved in human decision-making are part of the neural mechanisms underlying the certainty and common ratio effects. Specifically, we studied financial decisions involving the certainty and ratio effects in a person, K.C., who has extremely severe deficits in the ability to remember his past and imagine his future experiences despite the absence of other major cognitive deficits (Rosenbaum et al., 2005). His memory deficits resulted from brain damage sustained in a motorcycle accident. His injuries include extensive bilateral damage to the hippocampus and adjacent medial temporal lobe (MTL) structures. In extensive and cued autobiographical interviews, K.C. is unable to remember a single experience from his personal past and is similarly profoundly deficient in his ability to generate future and fictitious scenarios (Rosenbaum et al., 2009; Kwan et al., 2012, 2013), including those involving regret or rejoicing. Thus, K.C. provides a unique opportunity to test the role of anticipated regret in decision-making, a role that is central to much current research in psychology, economics, and cognitive neuroscience (e.g., Zeelenberg, 1999; Coricelli et al., 2005; Zeelenberg and Pieters, 2007; Sandberg and Conner, 2008).

We report that K.C., like healthy control participants, makes choices that exhibit both the certainty effect and the common ratio effect. Thus, these paradoxical effects are causally independent from the kinds of episodic prospection that K.C. lacks and from the hippocampal and medial-temporal lobe structures that were damaged in his motorcycle accident. These results are inconsistent with Loomes and Sugden's (1982) explanation of the certainty effect and the common ratio effect as the consequences of anticipated regret, and suggest that there are a variety of mechanisms for evaluating the future consequences of our decisions.

## MATERIALS AND METHODS

### Participants

One individual, K.C. (age = 61 years), with hippocampal damage and episodic amnesia, and 12 healthy controls (8 women and 4 men; age: $M = 68$ years, $SD = 7.5$) participated. The mean education level of the controls was 11.6 years ($SD = 2.9$ years). Their mean Mini Mental State Examination score was 28.9 ($SD = 0.9$), and mean Frontal Assessment Battery score was 17.4 ($SD = 0.5$). None had a history of neurological disorders, psychiatric disorders, or drug abuse. K.C. was tested on two separate occasions; control participants were tested once. K.C. gave informed written consent in accordance with the ethics review boards at York University and Baycrest and received monetary compensation for his time and travel expenses. For all participants, testing was done in accordance with the Declaration of Helsinki.

K.C. is a right-handed man with 16 years of formal education. In 1982, at the age 30, he sustained a closed head injury in a motorcycle accident. He has near-complete anterograde and retrograde amnesia for episodic memories (Tulving, 1985; Rosenbaum et al., 2005). K.C. also has near-complete deficits in the ability to imagine his personal future (Tulving, 1985; Rosenbaum et al., 2009; Kwan et al., 2012).

K.C.'s semantic memory and implicit memory are comparatively well-preserved and remained stable since the time of his accident (Rosenbaum et al., 2005). On generalized tests of cognitive function and dementia, he scores well above the diagnostic

threshold, and his failures are confined mostly to measures of memory. MRI scans reveal extensive cortical atrophy with substantial bilateral volume loss in the MTL, including the hippocampus and parahippocampal cortex. (For a neuroanatomical and neuropsychological review, see Rosenbaum et al., 2005.)

### Materials and Procedure

Participants were tested using a laptop computer. Two introductory screens asked participants to imagine that they have invested money in stocks and that a broker is asking them to choose between two possible options. In the experimental phase, participants were presented consecutively with 40 screens offering different binary choices between two hypothetical investments, one described on the left, and one described on the right. For each investment, the potential gain (or loss) and its associated probability were shown (e.g., 50% chance of earning \$750, 50% chance of earning \$0). Control participants read the screen and made a selection by clicking on the preferred investment. Because K.C.'s vision is poor, the test administrator read the contents of the screen aloud, and K.C. indicated his choice verbally. K.C. was administered the experimental tests on two occasions to ensure reliability. No feedback as to the outcome of their investment choices was provided to any of the participants.

Of the 40 choice trials presented, the first 4 were practice trials, and 12 others were fillers. Among the remaining 24 trials, 12 were choices between possible gains, and 12 were choices between possible losses. Within each set of 12 choices, 6 involved *high probability* outcomes, and 6 involved matched *low probability* outcomes in which the probabilities were reduced by a common factor so as to maintain a constant ratio of expected values across each matched pair. For example, one high probability gain trial involved a choice between a 100% chance of earning \$10,000 versus a 90% chance of earning \$15,000 with a 10% chance of earning nothing. The matched low probability gain trial involved a 10% chance of earning \$10,000 with a 90% of earning nothing versus a 9% chance of earning \$15,000 with a 91% chance of earning nothing.

Half of the pairs were like the preceding example, which according to Allais (1953) should result in a paradoxical preference change, at least in the controls. The other pairs involved choices in which the alternatives were of equivalent expected value (e.g., a high probability gain trial involving a 100% chance of earning \$10,000 versus a 90% chance of earning \$11,111 with a 10% chance of earning nothing, paired with a low probability gain trial involving a 10% chance of earning \$10,000 with a 90% chance of earning \$0 versus a 9% chance of earning \$11,111 with a 91% chance of earning nothing).

## RESULTS

We tested the hypothesis that anticipated regret is the basis for the certainty and common ratio effects (Allais paradox) with respect to gains, and the related hypothesis that anticipated rejoicing is the basis for these effects with respect to losses. If these hypotheses are correct, then because of K.C.'s extensive MTL damage and his inability to episodically imagine future events and anticipate his emotional responses to them, his choice behavior should differ significantly from that of controls. Therefore, according to the anticipated regret hypothesis, he should show neither the certainty effect nor the common ratio effect.

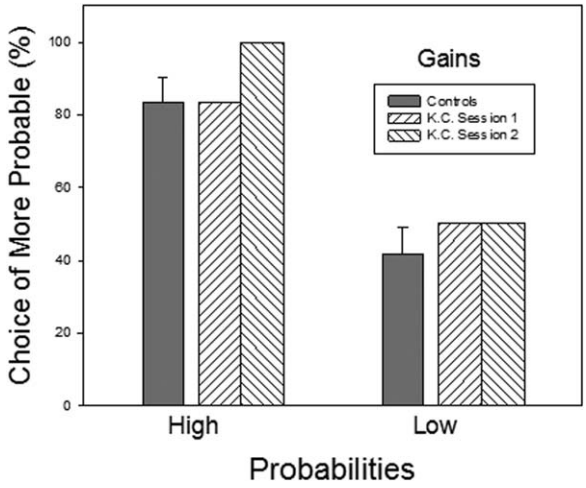


**FIGURE 1. Present choice of the more probable gain by K.C. and the controls. Error bars represent the standard error of the mean.**

With regard to gains, however, K.C., like the control participants, strongly preferred a certain gain over a probabilistic gain of equal or greater expected value on both testing occasions (see the results for the high probability choice trials depicted on the left side of Fig. 1). Specifically, averaged across both testing sessions, K.C. chose the certain gain on 91.7% of the high probability choice trials, and the controls, on average, chose the certain gain on 83.3% of the high probability choice trials. In fact, his behavior did not differ significantly from that of the controls based on Crawford and Howell's (1998) modified $t$ test for comparing performance of individual patients with a small control group, $t(11) < 1.0$, *ns*.

When the probabilities were reduced by a common factor, K.C. and the controls now chose the more probable of the two options on 50.0 and 41.7%, respectively, of the low probability choice trials (see the right side of Fig. 1), consistent with the common ratio effect. Again, K.C.'s choices did not differ significantly from those of the controls, $t(11) < 1.0$, *ns*. For the controls, the decrease in preference for the more probable gain from the high probability condition to the low probability condition was statistically significant, $t(11) = 4.19$, $P = 0.002$, and K.C.'s decrease in preference (41.7%) was virtually identical to that of the controls (41.6%).

So, too, K.C. and the controls strongly preferred a probabilistic loss over a certain loss of equal or lower negative expected value (a negative certainty effect). When the probabilities were reduced by a common factor, this preference disappeared, consistent with the Allais paradox. (Compare the results for the

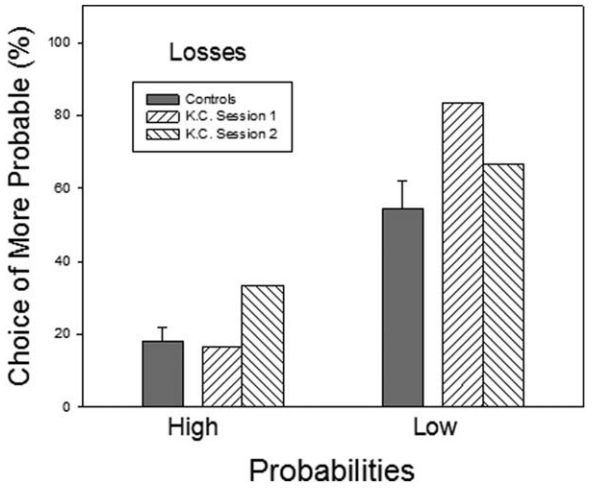


**FIGURE 2. Present choice of the more probable loss by K.C. and the controls. Error bars represent the standard error of the mean.**

high and low probability choice trials shown in Fig. 2). Again, K.C.'s choices did not differ significantly from those of the controls in either the high or the low probability condition. The change in preference for the controls (36.2%) was statistically significant, $t(11) = 3.53$, $P = 0.005$, and the change in preference for the controls was actually less, on average, than that for K.C. (50.0%).

## DISCUSSION

Our results show that K.C., a person with extensive MTL damage and episodic amnesia, exhibits Allaisian choice behavior with respect to both gains and losses that is indistinguishable from that of control participants. Because he is unable to construct events in his personal future and consequently unable to anticipate his emotional responses to such events, the fact that K.C. shows both positive and negative certainty effects and common ratio effects is contrary to the predictions of regret theory (Loomes and Sugden, 1982). The fact that these effects are independent of the capacity to episodically construct future experiences suggests that there are multiple mechanisms for evaluating the future consequences of one's decisions.

K.C.'s inability to episodically (re)construct events in his past and future is well-documented (Tulving, 1985; Rosenbaum et al., 2005). His deficit in future personal event construction was first described by Tulving (1985) and is apparent in the following conversation:

E.T.: Let's try the question again about the future. What will you be doing tomorrow?
K.C.: (pausing and smiling faintly) I don't know.
E.T.: Do you remember the question?
K.C.: About what I'll be doing tomorrow?
E.T.: Yes. How would you describe your state of mind when you try to think about it? (5 second pause).
K.C.: 'Blank,' I guess.

Encouraged to elaborate on this blankness, K.C. said, "It's like being in a room with nothing there and having a guy tell you to go find a chair, and there's nothing there," and, "It's like swimming in the middle of a lake. There's nothing there to hold you up or do anything with".

K.C.'s inability to episodically construct future events was recently confirmed in a modified Autobiographical Interview using Galton–Crovtiz cuing in which, when asked about specific future events in his life, K.C. was unable to generate a single episodic descriptor (Kwan et al., 2012). Similar deficits in episodic future event construction and scene construction have been reported in other people with episodic memory deficits due to MTL damage (e.g., Klein et al., 2002; Hassabis et al., 2007; Race et al., 2011), and based on the present findings, we would predict that such individuals also would make Allaisian choices despite an inability to anticipate their emotions.

K.C. clearly understands what it means to regret something. He describes a regret as, "something you wish you hadn't done," and he says that 'inside," people with regret feel, "angry at themselves." He says that regret is something that might lead one to try to undo it or, "make it right." K.C. says that he would be, "angry at himself," in scenarios (based on Connoley and Zeelenberg, 2002) that involve reckless losses (e.g., gambling away money your mother gave you to buy clothing) and missed opportunities (e.g., declining an invitation to a Toronto Blue Jays game in which the pitcher throws a no-hitter). He also appears to recognize the semantic distinction between regretting one's decision and being disappointed in an outcome (Marcatto and Ferrante, 2008). It should be underscored that K.C. denies that he imagines himself potentially losing money when making his decisions in the Allais task. He says instead that he decides by choosing what seems like the better deal or simply that he, "goes for the money." Furthermore, K.C. claims to have no regrets. These statements are consistent with the claim that K.C. does not construct future experiences of regret and that he does not consider the possibility of future regret in making his Allaisian choices.

Why K.C. (and others) exhibit Allaisian behavior is, of course, open to debate. The most parsimonious explanation is provided by prospect theory (Kahneman and Tversky, 1979), according to which Allaisian choices reflect the curvature of the probability weighting function and do not involve anticipation of emotional responses, and no role for episodic anticipation is assumed. However, even if episodic anticipation is not necessary, it could modulate the extent to which one exhibits Allaisian behavior. It also is possible that anticipation is multidimensional, with procedural, semantic, affective, and/or episodic components, each of which might operate more or less independently of the others. If so, the certainty and common ratio effects might be due to nonepisodic forms of anticipation, although such alternative hypotheses cannot be tested until they are formulated precisely. Moreover, if such nonepisodic forms of anticipation are the basis for the certainty and common ratio effects, then the present results imply that these forms are independent of episodic anticipation.

Fundamentally, the present findings suggest that episodic future construction processes are less relevant to Allaisian decision-making than one might expect based on recent research linking decision-making to MTL functions (Atance and O'Neill, 2001; Suddendorf and Bucy, 2005; Schacter et al., 2007; Boyer, 2008; Peters and Büchel, 2010). Our results underscore the need for caution in assessing the role of future event construction in human decision-making (see also Klein, 2013). They also add to a recent body of evidence showing that significant aspects of K.C.'s decision-making capacity are spared despite his global deficits in episodic memory and future event construction. As with other amnesic individuals and control participants, K.C.'s choices are sensitive to amount, probability, and delay of reward (Kwan et al., 2012, 2013). Asked how he makes choices, he says he chooses what seems to be the best option. Asked how he will spend the money, he says he will put it in the bank; queried further, he often says he will spend the money on beer. Despite the fact that K.C.'s decision-making does not appear to have input from episodic future construction systems, he nonetheless exhibits many of the key features of typical human decision-making.

Human decision-making involves multiple cognitive systems, and episodic event construction and the anticipation of emotions may play a role in some forms of decision-making. As Klein et al. (2002) and Klein (2013) have argued, however, they should not be presumed to play a role in all forms of decision-making. Individuals who lack the capacity for episodic event construction with respect to the past and the future due to hippocampal damage allow scientists the unique opportunity to determine which aspects of decision-making are independent of episodic construction processes. Robust behavioral economic phenomena, such as delay and probability discounting (Green and Myerson, 2004) and the Allaisian choice tasks used in the present study, can be used to assess the differences between the decision-making of amnesic individuals and controls as part of developing a fuller account of human decision-making that distinguishes between necessary and modulatory cognitive mechanisms.

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