Biological correlates of the Allais paradox - updated

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1. Introduction

Expected utility theory, the theory of risky decision-making considered in mainstream economics, cannot accommodate the Allais (1953) paradox, a puzzle that ubiquitously emerges in questionnaires. Consider the two pairs of situations (described in detail in Section 2, Materials and Methods): A and B; along with C and D. Situation A is the certainty of receiving 100 million, whereas Situation B is a 10 percent chance of winning 500 million, an 89 percent chance of winning 100 million, and a 1 percent chance of winning nothing. Situation C is an 11 percent chance of winning 100 million and an 89 percent chance of winning nothing, whereas Situation D is a 10 percent chance of winning 500 million and a 90 percent chance of winning nothing. Expected utility theory predicts that the preference of A over B should entail the preference of C over D, and conversely. However, people often violate this theory.

Allais himself explains the paradox by the expected utility theory's neglect of two basic psychological features: (1) the nonidentity of monetary and psychological values, and (2) the distribution of utility, as a whole, about the mean, rather than the mathematical expectation of utility only (Allais, 2008). When very large sums are involved in comparison with the psychological capital of the subject, there is strong interdependence between the different gambles and their probabilities. Further, this entails a preference for security in the neighborhood of certainty.

Preference of A over B should entail the preference of C over D, according to expected utility theory, as mentioned. However, expected utility theory accommodates competing risk preferences. The theory only requires that once preference of B over A occurs, for example, this should entail the preference of D over C. Although there are several studies relating biological variables to risk preferences (as surveyed below), there is none relating the Allais counterexample itself to biological characteristics.

Consequently, we investigate whether a subject's biological trait makes him or her more prone to display the paradox. The results of studies relating biological variables to risk preferences suggest that the Allais paradox itself should be related to biological characteristics.

We apply the variants of the Allais example used by Kahneman and Tversky (1979) to 120 student subjects. We also apply a presurvey questionnaire to gather information about a subject's gender and age, whether they have children, their second- to fourth-digit ratio, current emotional state, perceived negative life events, and whether they believe in God. We find that particular states of these "biocharacteristics" are related to the paradox.

The remainder of this article is organized as follows. Next, we provide a brief overview of the findings regarding the above biocharacteristics in relation to risk. This aims to justify our own selection of the characteristics in the presurvey questionnaire. Then, in Section 2, we explain the Allais paradox in detail and the test statistics used to study the same. The contents of the questionnaire (the questions responded to by the participants) are then described in connection with the Allais paradox, followed by the details of data collection from the sample subjects. Finally, we present the results (Section 3) and a conclusion (Section 4).

Risk attitudes and their relation to biological characteristics

The biological roots of decision-making under risk do matter. Now, we provide a brief overview of previous findings to justify this statement. Among the several studies relating biological variables to risk preferences, the studies on twins (Barnea *et al.*, 2010; Cesarini *et al.*, 2009a; Cesarini *et al.*; 2009b, Zhong *et al.*, 2009a), molecular genetics studies (Crisan *et al.*, 2009; Dreber *et al.*, 2009; Kuhnen and Chiao, 2009; Roiser *et al.*, 2009; Zhong *et al.*, 2009b; Zhong *et al.*, 2009c), and hormonal studies (including digit ratio; Chen *et al.*, 2005; Apicella *et al.*, 2008; Coates and Page, 2009; Pearson and Schipper, 2009; Sapienza *et al.*, 2009; Zethraeus *et al.*, 2009) are worth mentioning. Here, we focus on the following biocharacteristics: gender, age, parenthood, handedness, second- to fourth-digit ratio, current emotional state, perceived negative life events, and religiousness.

Gender

Gender differences may be important for preferences in general and risk preferences in particular (Croson and Gneezy, 2008). Generally, women are more risk-averse. Portfolios of single women are commonly less risk-oriented than those of single men. Female risk-aversion may arise from the fact that women are relatively more pessimistic and insensitive to probabilities. However, all the experimental evidence may be framing-dependent (Byrnes *et al.*, 1999, present a meta-analysis of the results in literature). Men are also believed to be more overconfident than women (Barber and Odean, 2001), and this has already been related to their biocharacteristics (Zindel *et al.*, 2010). Because overconfidence leads to overtrading and lower returns, men appear to be less “rational” than women in this matter (Da Costa Jr. *et al.*, 2008). Thus, we will look for explicit correlations between a subject’s gender and their pattern of violation of expected utility theory through the Allais paradox.

Risk preferences and menstrual cycle may be related, too (Chen *et al.*, 2005; Pearson and Schipper, 2009). Thus, we also find it worthwhile to focus on the particular female characteristics “ovulation” and “menstruation,” which are related to hormonal changes. The onset of menstruation corresponds closely with the hormonal cycle, and women may experience emotional disturbances associated with menstruation. Women’s sexual desire also changes near ovulation, and this may interfere with their decision-making under risk and, perhaps, with their propensity to display the Allais paradox.

Thus, we asked in our presurvey questionnaire whether female subjects were either ovulating or menstruating. These biocharacteristics were then related to the pattern of violation of expected utility theory in the questionnaire. (Eckel and Grossman, 2008, provide an excellent survey on the relationship between sex differences and risk.)

Here, we find that gender differences and menstrual cycle do matter. In our experiment, men were more prone to the Allais paradox. Among the women, those who were menstruating at the time of the experiment were more predisposed to display the paradox.

Age

In the case of behavior, age is considered important. In particular, age is correlated with risk-taking (Dohmen *et al.*, 2005). For instance, unlike adults, kids are risk-lovers (Moreira *et al.*, 2010). There is not much difference between the brains of a 25-year-old youth and a 75-year-old person. However, in the years between the age of 10 and the mid-20s, hormonal factors trigger a need to impress peers by reckless behavior, and this generates an inability to perceive risks accurately. Moreover, an urge for "sensation-seeking" reaches a peak during the late teen years and then declines gradually throughout life. Those who have a greater inclination to sensation-seeking tend to have higher levels of testosterone than others (Campbell *et al.*, 2010, relate sensation-seeking to testosterone levels and discuss previous research on this topic). Sensation seekers also tend to have low levels of monoamine oxidase, an enzyme that regulates serotonin, which in turn regulates mood. People with low monoamine oxidase levels tend to smoke and drink more than others and are more likely to have a criminal record. All these considerations allow us to conjecture that people below 25 years of age show a pattern of behavior related to the Allais paradox, which may be different from that of older subjects.

In particular, we also conjecture that the mother's age at delivery affects a boy's predisposition to the Allais paradox. Boys born to young mothers are at high risk of committing crimes in adolescence. Maternal rejection, erratic behavior on the part of parents, and lack of parental supervision are among the best predictors of juvenile delinquency. Having a teenage mother roughly doubles a boy's propensity to commit crime. (Lee *et al.*, 2008, provide an overview that delves deeper by studying the neural basis of the relationship between age and risk-taking.)

In this study, we find that boys born to young mothers (a variable measured by taking the mother's current age minus son's age ≤ 25 years) were less prone to displaying the Allais paradox; nevertheless, we did not find any role for age per se.

Parenthood

Growing kids alters parental behavior (and perhaps, indirectly, one's attitude toward risk) because neural and hormonal interactions are involved in nurturing babies. Estrogen triggers an increase in oxytocin (a hormone that promotes bonding patterns) in the expectant mother, which promotes maternal behavior. Prolactin also promotes care-giving behavior and directs brain reorganization to favor maternal behavior. The live-in father's oxytocin levels also increase toward the end of his partner's pregnancy. Vasopressin (known as the "monogamy hormone") also plays a role in the father by promoting brain reorganization toward paternal and family-bonding behavior. Vasopressin can reinforce the father's testosterone level and induce him to protect his mate and child; however, it also tempers his aggression, making him less capricious. The father's prolactin levels also increase after cohabitation with the child. Elevated prolactin levels, in both the nursing mother and the involved father, cause some reduction in their testosterone levels, even though they also elevate the levels of the pleasure hormones known as opioids. Fathers usually have lower salivary testosterone levels than unmarried men and married nonfathers. (On this subject, see Storey *et al.*, 2000; Berg and Wynne-Edwards, 2001; Gray *et al.*, 2002; and references therein.)

We thus conjecture that parenthood may be related to whether a subject is more or less prone to violate expected utility theory. Furthermore, we find that childless subjects are more prone to showing the Allais paradox.

Handedness

Approximately 10–13 percent of any population is left-handed. However, no one knows the exact reason why the right-handed human population is predominant. Genetics certainly plays a role, but it is not the only factor causing left-handedness. For instance, even when both parents are left-handed, there is only a 26 percent chance of their child being left-handed. The proportion of left-handers has remained constant over a long period of 30,000 years. This suggests that there is an evolutionary role for left-handers, who possess a "surprise" factor during combat; moreover, the forces causing left-handedness are independent of culture.

Left-handed people occupy the extremes when it comes to health and ability. Left-handed people have IQs greater than 140 in comparison to right-handed people. Left-handedness has also been associated with talent in music and sports. This may partly be because left-handers have an intrinsic neurological advantage over right-handers. Males are three times more likely to be left-handed than females. Homosexuals may be up to 39 percent as likely to be left-handed as heterosexuals. Left-handedness has also been linked to epilepsy, Down's syndrome, autism, and mental retardation. Left-handed peoples' life spans are shorter than those of their right-handed counterparts by as much as 9 years, which in part may be due to the prevalence of right-handed tools in society: thus, left-handers are more prone to accidents. (See Llaurens *et al.*, 2009;

Corballis, 1997; Raymond *et al.*, 1996; and references therein for a full discussion of left-handedness.)

All these arguments allow us to conjecture that risky choices may be made differently by left-handed people. Left-handers may also display a pattern of violation of expected utility theory distinct from that of right-handers. This study suggests that right-handers are more susceptible to the Allais paradox, although the result from our sample lacks a statistical significance.

Second- to fourth-digit ratio

The ratio between the lengths of the second and fourth digits is claimed to be a marker for prenatal testosterone exposure and may influence choice under risk. It may also be related to a subject's predisposition to the Allais paradox. It is claimed that high-testosterone men can be tracked by a relatively long ring finger. Men tend to have lower values of 2D:4D (~0.98) than women (~1), that is, men have relatively shorter index fingers (2D) compared to ring fingers (4D). Low digit ratios are caused by high prenatal testosterone exposure, low prenatal estrogens, or both. Low digit ratios in men are associated with higher sperm numbers, good health, physical aggression, enhanced fairness considerations, greater number of sexual partners and greater number of children fathered, superior athletic and musical ability, and higher levels of courtship behavior in the presence of potential mates.

High testosterone levels may affect economic decisions. In ultimatum game experiments, low-digit-ratio high-testosterone men tend to lose their drive for a good deal after viewing sexy pictures, a result also replicated for salivary testosterone. However, whether digit ratio really correlates with risk preferences is still unsettled (see, for example, the results in Apicella *et al.*, 2008), and the pattern of digit ratio might not be robust across ethnicities either (Pearson and Schipper, 2009). (Voracek and

Loibl, 2009, provide a comprehensive survey of the digit-ratio literature, and Manning, 2002, is the key reference.)

Herein, we measured the lengths of the fingers on the right hands of the subjects with a caliper and then calculated the digit ratios. We found that men with relatively longer index fingers, that is, men with low prenatal testosterone exposure, are more likely to express the Allais paradox.

Emotional state

Emotions surely play a role in one's attitude toward risk, although this is ignored by expected utility theory. Emotional states clearly influence financial decisions (Ackert *et al.,* 2003). For instance, investors in a good mood are more risk-averse (Isen *et al.,* 1988), and anxiety tends to make them prone to choose gambles with low-risk payoffs. Fear can discourage people from taking advantageous gambles, although insufficient fear can produce nonmaximizing behavior in the presence of risky options of negative expected value. Sadness makes people prone to choose gambles of high-risk payoff. In contrast, anxiety tends to make people prone to choose gambles with low-risk payoffs. In addition, fearful people usually make pessimistic risk assessments, whereas angry people tend to make optimistic risk assessments (Lerner and Keltner, 2000; also refer the discussion of literature in Lerner and Keltner, 2001).

Risk-averse behavior may be governed by immediate responses to fear, which occur in the amygdala. The brain has evolved to make emotional and rational decisions, in addition to adopting controlled and automatic decisions (Camerer *et al.*, 2005). Controlled and rational decisions can either cooperate or compete with automatic and emotional decisions. Cost-benefit analysis only makes sense for controlled and rational decisions, and rational decision-making depends on prior accurate emotional processing

(Bechara and Damasio, 2005). Emotion can be beneficial to decision-making when it is integral to a task; however, it can also be disruptive when unrelated to the task.

Initially, we conjecture that emotional states are related to predisposition to the Allais paradox. In this study, we consider a very direct model to assess basic emotional states: a continuous affect scale, ranging from “very anxious” and “moderately anxious” to “emotionless,” “moderately excited,” and “very excited.” We find that except for the characteristic “very anxious,” all the others show a relation with the manifestation of the Allais paradox. In particular, in the absence of emotions such as anxiety and excitement, people are more inclined to show the paradox.

We also track, as shown in Figure 1, the emotions of the subjects using the model of the affective circumplex (Russell, 1980) because it arguably helps to explain both current research and clinical findings that are at odds with models of basic emotions, such as the representation described in the previous paragraph (Posner *et al.*, 2005). The circumplex model proposes that all affective states arise from two fundamental neurophysiological systems—one related to valence (a pleasure–displeasure continuum), and the other related to arousal or alertness. Each emotion can be understood as a linear combination of these two dimensions or as varying degrees of both valence and arousal. The circumplex model is believed to complement data from developmental, neuroimaging, and behavioral-genetics studies of affective disorders (Posner *et al.*, 2005). In this study, we find that emotions, as measured by the affective circumplex, also are important for the manifestation of the Allais paradox. We find that not aroused, not excited, unhappy, quiet, and tired people are more prone to show the paradox.

We also consider the role of reported negative life events. In general, normal people who react more emotionally to negative life events tend to be more risk-averse than average people. For some people, negative life events and depression are related. Women report slightly more number of negative life events than men do. Despite this fact, women are actually only as vulnerable to negative life events as men are; only their perceptions differ (Dalgard *et al.*, 2006). We thus consider this particular biological trait and conjecture that negative life events not only influence one's attitude toward risk but also one's predisposition to show the Allais paradox. In our questionnaire, we asked subjects to report their perceived negative life events on a scale of 0–10, ranging from a few negative events to many. We found that the subjects reporting only few negative life events were more prone to manifestation of the Allais paradox.

Religiousness

Although it sounds odd superficially, religiousness can also be considered a biological trait. This is so because there is a neurological and evolutionary basis for religious experiences. "Neurotheology" studies the human urge for religious myths from a neurological point of view. The facts about the biocharacteristics of theists have been unearthed by neurotheology. There may be a hormonal basis for theism, too. Studies using positron-emission tomography find a relationship between low serotonin levels and self-transcendence for male subjects, a personality trait covering religious behavior and attitudes. The serotonin system may serve as a biological basis for spiritual experiences and may explain why people vary greatly in spiritual zeal. The latter may also have a genetic basis. (Religiousness as a biological trait is discussed in the studies by Ramachandran *et al.*, 1997; and Joseph, 2002.)

Thus, it makes sense to argue that religiousness may interfere with both behavior and one's attitude toward risk. We go further and conjecture that religiousness may also be related to the predisposition of a subject to incur in the Allais paradox. Indeed, here we find that God-believers are more susceptible to the Allais paradox, although this result lacks statistical significance.

The following section discusses the Allais paradox in more detail, along with the test statistics employed herein to track it.

2. Materials and methods

Allais paradox

Consider the example given in the Introduction again. Take two pairs of lotteries: A and B, along with C and D.

A	B
the certainty of receiving 100 million	a 10 percent chance of winning 500 million an 89 percent chance of winning 100 million a 1 percent chance of winning nothing
C	D
an 11 percent chance of winning 100 million an 89 percent chance of winning nothing	a 10 percent chance of winning 500 million a 90 percent chance of winning nothing

Expected utility theory predicts that preference of A over B should entail the preference of C over D, and conversely. However, people often violate that in questionnaires.

Expected utility theory is consistent with both answers AC and BD. Violations of the theory refer to the answers AD and BC. The fact that the violations in the questionnaires are mostly of the type BC, and not of the type AD, suggests that they are systematic (Conlisk, 1989). Here, it is useful to identify two patterns of violations of expected utility theory.

Pattern 1. Violations comprised of the answers AD and BC.

Pattern 2. Most answers are of the type BC rather than of the type AD (violations are systematic).

For testing Pattern 1, two groups of subjects and the test statistic *d* are taken into account (Conlisk, 1989). The two groups considered in this study refer to the binary forms of our biocharacteristics, for example, male versus female, subjects aged 25 and below versus subjects aged above 25, and so on (Table 1).

The test statistic *d* tracks the difference in the strength of Pattern 1 between two groups. It has approximately a standard normal distribution under the null hypothesis that Pattern 1 is equally strong for the two groups and can be defined as

$$d = \frac{V_I - V_{II}}{\sqrt{\frac{V_I(1-V_I)}{N_I - 1} + \frac{V_{II}(1-V_{II})}{N_{II} - 1}}} \tag{1}$$

where V (for violations) is the fraction of subjects who violate expected utility theory by giving the answers AD and BC, that is,

$$V = \frac{n(\mathrm{AD}) + n(\mathrm{BC})}{N}, \tag{2}$$

where $n(\mathrm{AD})$ is the number of subjects answering A and D, $n(\mathrm{BC})$ is the number of subjects answering B and C, and N is the sample size. The two groups are labeled *I* and

II. An improbably large positive value of *d* relative to the Gaussian provides evidence that Pattern 1 is stronger in Group *I* (Conlisk, 1989). (Observe that the equation (2) should refer separately to either Group *I* or Group *II* when calculating *d* using equation (1).)

Pattern 2 can be tested using the following test statistic *Z* (Conlisk, 1989):

$$Z = \frac{(S-0.5)\sqrt{N-1}}{\sqrt{\frac{0.25}{V} - (S-0.5)^2}} \tag{3}$$

where *S* (for systematic) is the fraction of violators who give the answer BC rather than AD, that is,

$$S = \frac{n(\mathrm{BC})}{n(\mathrm{BC}) + n(\mathrm{AD})}. \tag{4}$$

This test statistic *Z* has approximately a standard normal distribution under the null hypothesis that violations of expected utility theory are purely random. Positive values of *Z* indicate systematic violations, and an improbably large *Z*-value relative to the Gaussian provides evidence of Pattern 2 (Conlisk, 1989).

We apply these tests to the data gathered in the questionnaire below and to the presurvey questionnaire conveying information about the biocharacteristics of the subjects.

Questionnaire

The subjects were asked the following questions, which draw on the questionnaire proposed by Kahneman and Tversky (1979).

The first two pairs of questions are as follows.

Question 1	
Choose between	
A	B
\$2,500 with probability 33% \$2,400 with probability 66% \$0 with probability 1%	\$2,400 with certainty

Question 2	
Choose between	
C	D
\$2,500 with probability 33% \$0 with probability 67%	\$2,400 with probability 34% \$0 with probability 66%

Kahneman and Tversky reported that most people usually choose B for Question 1 and choose C for Question 2. Assuming that the utility $u(\$0) = 0$, the choice of B in Question 1 means $0.34u(\$2,400) > 0.33u(\$2,500)$. However, the choice of C in Question 2 implies the reverse inequality. This constitutes a violation of expected utility theory.

The subsequent pairs of questions are 3 and 5 along with 4 and 6. These represent more variants of the Allais example, highlighting the choice of risky prospects in the domains of both gains and losses respectively.

Question 3	
Choose between	
A	B
$4,000 with probability 80%	$3,000 with certainty

Question 4	
Choose between	
A	B
A loss of $4,000 with probability 80%	A loss of $3,000 with certainty

Question 5	
Choose between	
C	D
$4,000 with probability 20%	$3,000 with probability 25%

Question 6	
Choose between	
C	D
A loss of $4,000 with probability 20%	A loss of $3,000 with probability 25%

Kahneman and Tversky observed that the majority of subjects usually choose B in Question 3; and C in Question 5. The choice of B in Question 3 implies that $u(\$3,000)/u(\$4,000) > 4/5$, whereas the choice of C in Question 5 implies the reverse inequality. However, most subjects usually choose A in Question 4, and D in Question

6. This shows that the preference between gambles of negative outcomes is the mirror image of the preference between gambles of positive outcomes.

The next pair (Questions 7 and 8) shows a version of the Allais example for nonmonetary outcomes.

Question 7	
Choose between	
A	B
A three-week tour of England, France, and Italy with probability 50%	A one-week tour of England with certainty

Question 8	
Choose between	
C	D
A three-week tour of England, France, and Italy with probability 5%	A one-week tour of England with probability 10%

Kahneman and Tversky noted that most subjects usually choose B in Question 7, but choose C in Question 8.

The next pair (Questions 9 and 10) refers to situations where winning is possible but not probable, and most people choose the gamble that offers the largest gain. The last pair (Questions 11 and 12) shows the mirror image for losses.

Question 9	
Choose between	
A	B
$6,000 with probability 45%	$3,000 with probability 90%

Question 10	
Choose between	
C	D
\$6,000 with probability 0.1%	\$3,000 with probability 0.2%

Kahneman and Tversky's experiment showed that the majority of subjects choose B in Question 9, which implies that $0.9u(\$3,000) > 0.45u(\$6,000)$. However, they choose C in Question 10, which implies the reverse inequality.

Question 11	
Choose between	
A	B
A loss of \$6,000 with probability 45%	A loss of \$3,000 with probability 90%

Question 12	
Choose between	
C	D
A loss of \$6,000 with probability 0.1%	A loss of \$3,000 with probability 0.2%

In the Kahneman–Tversky questionnaire, most subjects choose A in Question 11, which implies $0.45u(-\$6,000) > 0.90u(-\$3,000)$. However, they choose D in Question 12, which implies the reverse inequality.

Note that all the answers in the Kahneman–Tversky questionnaire represent violations of the type AD or BC. Violations of the type BC occurred for the pairs (1, 2), (3, 5), (7, 8), and (9, 10), and violations of the type AD occurred for losses, that is, for the pairs (4, 6) and (11, 12), as the mirror image.

Next, we present our own experiment related to such pairs of questions. Moreover, we investigate how the biological characteristics of the subjects may be related to violations of expected utility theory.

Data

These questions were distributed to 120 genetically unrelated subjects (62 males and 58 females) studying in the Federal University of Santa Catarina, Brazil. These students were from the streams of economics, accounting, production engineering, and library science. The column "number of subjects" in Table 2 shows the valid number of answers to each pair of questions. The presurvey questionnaire asking for the respondents' biocharacteristics preceded the questionnaires. Table 1 shows the description of the groups for every biocharacteristic.

3. Results

First, we investigated the occurrence of Pattern 2 in the responses given to each pair of questions described above; that is, we assessed whether violations of expected utility theory in our experiment are significantly systematic. As mentioned, systematic violations mean that most answers are of the type BC rather than of the type AD.

Table 2 shows the results of the test statistic Z described by equation (3). Positive values of Z indicate systematic violations, and large Z-values relative to the Gaussian ($Z > 2.00$) provide evidence of Pattern 2. Table 2 shows that the Z-values (in bold) are large (that is, greater than 2.00) for every pair of questions. This suggests that the Allais paradox appears in our experiment in all the versions presented and that such violations of expected utility theory are systematic.

As for the role that the biocharacteristics of the subjects play, Table 3a shows the results for the test statistic *d* (described by equation (1)) for the pairs of questions that consider the subject groups presented in Table 1. The statistic *d* tracks the differences in the strength of Pattern 1 (that is, violations of expected utility theory expressed through the answers AD and BC) between the two groups, *I* and *II*, as defined in Table 1. Large positive values of *d* relative to the Gaussian ($d > 2.00$) provide evidence that Pattern 1 is stronger in Group *I*. Conversely, large negative values establish that Pattern 1 is stronger in Group *II*. Values in bold in Table 3a show the significant cases. Excluding the biocharacteristics "handedness" and "religiousness," all the remaining factors are statistically significant for at least one pair of questions.

Table 3a shows that the subjects' inclination to display the Allais paradox while choosing between risky prospects depends on the following biocharacteristics: gender, menstrual cycle, mother's age at delivery, parenthood, digit ratio, perceived negative life events, and emotional state. (Observe that although the biocharacteristic "age" is not significant, "mother's age at delivery" is.) Those who are more likely to show the paradox are (1) men subjects, (2) menstruating women, (3) boys born to young mothers, (4) childless subjects, (5) men with relatively longer index fingers, that is, with low prenatal testosterone exposure, (6) subjects who reported few negative life events, and (7) subjects reporting an emotional state of lack of anxiety, excitement, or arousal, in addition to those who were unhappy, quiet, and tired.

Using the covariates in Table 1, we also ran a logistic regression for each pair of questions to ensure robustness. Here, the response variable assumes the value one for the answers AD and BC, and the value zero, otherwise. Only the covariates shared by both sexes were considered; thus, we dropped menstrual cycle, mother's age at delivery, and digit ratio. We did not consider the sexes separately because this procedure would render the sample size smaller and thus insufficient. The covariates were selected by the stepwise method. Table 3b shows the coefficients estimated by maximum likelihood. Values in parentheses are the corresponding *p*-values based on the Wald chi-square statistics. Values in square brackets are the associated odds ratios. An odds ratio > 1 means a greater probability of violation of expected utility. The results show the contribution of a covariate for the probability of violation through either answer AD or BC. As can be seen, they are in accordance with the results in Table 3a, which considers the statistic *d*.

Table 4a shows the answers given by the groups for the pairs of questions where a biocharacteristic presents a significant statistic *d* in Table 3a. As observed, evidence of the Allais paradox is given by the answers AD and BC. Positive (negative) *d* values are related to Group *I* (Group *II*). Violation of expected utility theory through the answer BC is the commonest for most biocharacteristics (that is, violations are systematic), except for "menstrual cycle." Also note that *d* is significant for both types of answers AD and BC for the pairs that are mirror images for losses, that is, the pairs (4, 6) and (11, 12). Moreover, Table 4b shows that the results using simple logistic regressions are in accordance with those using the statistic *d*.

Table 5a shows the answers given by the subjects with reference to their handedness and religiousness. Although the statistic *d* is not statistically significant in both cases ($d < 2.00$), there is a clear tendency for the subjects to give the answers AD and BC, the answer BC being the commonest (that is, violations of expected utility are systematic). (Intriguingly, no left-hander gave the answer AD.) The positive *d* values in Table 5a are related to Group *I*, that is, right-handers and theists (Table 1). Thus, left-handers and atheists are less prone to display the Allais paradox. In our sample, 21 percent was constituted by atheists, and left-handers comprised 9.2 percent. We speculate that a sample greater than 231 subjects will confirm the pattern shown in Table 5a, with a *d* value > 2.00. Furthermore, Table 5b shows that the results using logistic regressions are consistent with those using the statistic *d*. Similar to the statistic *d*, the estimated coefficients were not statistically significant in both cases. However, in both cases, there is a clear tendency for the subjects to give the answers AD and BC, the answer BC being the norm.

4. Conclusion

We replicated the Allais example in relation to the choice of alternative prospects in a sample of 120 student subjects. In addition, we show that the following biocharacteristics are closely related to the propensity of a subject to display the Allais paradox: gender, menstrual cycle, mother's age at delivery, parenthood, digit ratio, perceived negative life events, and emotional state. The Allais paradox is more probable in (1) men subjects, (2) menstruating women, (3) boys born to young mothers, (4) childless subjects, (5) men with low prenatal testosterone exposure, (6) subjects who reported having experienced few negative life events, and (7) subjects reporting an emotional state lacking anxiety, emotion, excitement, and arousal, in addition to those who were unhappy, quiet, and tired.

Right-handers and theists seemed to be more susceptible to the Allais paradox, although this result was not statistically significant. However, we speculate that a larger sample will replicate this finding.

In other words, our study suggests that women, particularly when not menstruating, are more "rational" in that they are less susceptible to the Allais paradox. Those born to not-too-young mothers and men who have fathered kids are more rational. Those with high prenatal testosterone exposure and with many negative life events are also more rational. Anxious, excited, alert, happy, active, and fresh people are also more rational, in addition to left-handers and atheists.

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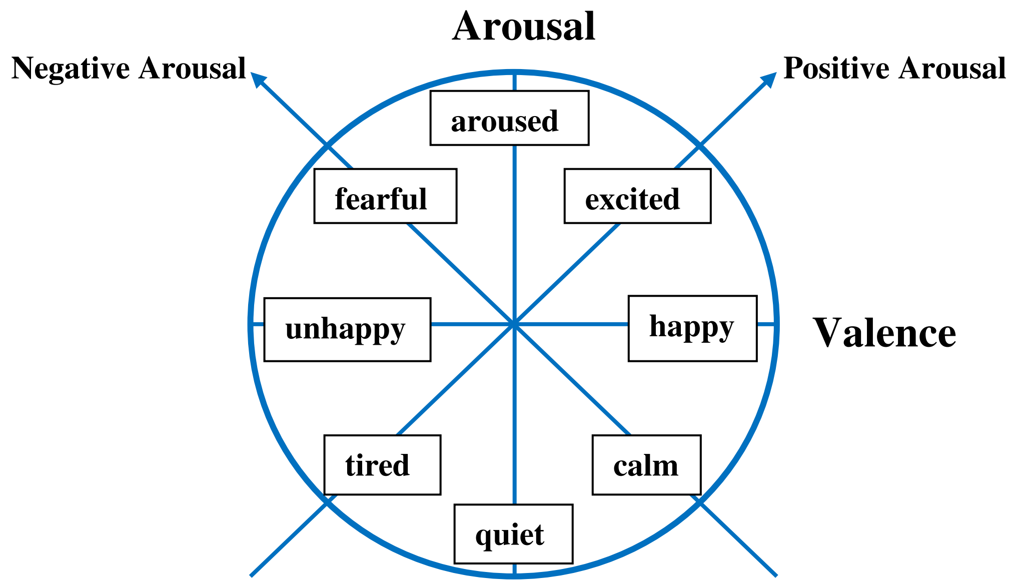

Figure 1. Affective circumplex: a graphical representation of the circumplex model of affect, with the horizontal axis representing the valence dimension and the vertical axis representing the arousal or activation dimension.

Table 1. Group description for every biocharacteristic

Biocharacteristic	Group *I*	Group *II*
gender	female	male
menstrual cycle	menstruating	otherwise
age	age < 25	age ≥ 25
mother's age	(mother's age – boy's age) ≤ 25	otherwise
marital status	single	otherwise
parenthood	having children	otherwise
handedness	right-hander	left-hander
digit ratio	male with digit ratio 2D:4D < 1	otherwise
negative life events	few (≤ 5)	many (> 5)
emotional state 1	very anxious	otherwise
emotional state 2	moderately anxious	otherwise
emotional state 3	emotionless	otherwise
emotional state 4	moderately excited	otherwise
emotional state 5	very excited	otherwise
affective circumplex 1	aroused, excited. or happy	otherwise
affective circumplex 2	quiet or tired	otherwise
religiousness	theist	atheist

Table 2. Systematic violations of expected utility theory in every pair of questions

Pair of questions	Systematic violations	Nonsystematic violations	Number of subjects	*Z*-value
(1, 2)	42	13	108	**4.20**
(3, 5)	54	18	113	**4.61**
(4, 6)	45	19	112	**3.40**
(7, 8)	61	9	116	**7.58**
(9, 10)	68	7	112	**9.40**
(11, 12)	42	14	114	**3.98**

Note: The test statistic Z has approximately a standard normal distribution under the null hypothesis that violations of expected utility theory are purely random. Positive values of Z indicate systematic violations, and large (bold) Z-values (> 2.00) relative to the Gaussian provides evidence of Pattern 2 (that is, most answers are of the type BC rather than of the type AD).

Table 3a. Test statistic *d* for every pair of questions answered by the groups in Table 1

Biocharacteristic	Pair of questions					
	(1, 2)	(3, 5)	(4, 6)	(7, 8)	(9, 10)	(11, 12)
gender	**–2.34**	0.59	–0.81	–0.07	**–2.07**	–0.58
menstrual cycle	–0.08	–0.46	**2.17**	0.00	–0.40	–0.42
age	–0.84	–0.33	–0.36	–0.48	–0.34	–0.53
mother's age	0.62	**–2.07**	0.90	1.08	–0.04	1.01
marital status	0.35	1.93	1.77	0.48	**2.52**	–0.35
parenthood	–0.67	–0.91	–1.14	–0.63	**–3.21**	0.67
handedness	–1.17	0.52	0.73	1.67	0.00	–0.08
digit ratio	–0.16	0.51	**–2.03**	**–2.25**	–0.81	0.50
negative life events	–0.37	**2.29**	–1.75	–0.59	–1.03	–0.95
emotional state 1	–0.39	0.33	1.25	–0.09	–0.87	0.94
emotional state 2	1.78	–0.39	0.07	–0.04	–0.62	**–2.02**
emotional state 3	0.55	–1.08	0.69	1.22	1.31	**4.57**
emotional state 4	**–2.88**	0.84	–1.27	0.66	0.04	–1.41
emotional state 5	0.95	0.33	–0.47	**–2.04**	1.06	1.07
affective circumplex 1	–1.16	–0.32	–0.83	–0.17	–0.03	**–2.31**
affective circumplex 2	–0.55	–0.26	0.23	–0.72	–0.06	**2.62**
religiousness	0.85	1.47	–0.54	–0.36	–0.75	0.87

Note: The test statistic *d* tracks the difference in the strength of pattern 1 (that is, violations of expected utility theory through the answers AD and BC) between the two groups, *I* and *II*, as defined in Table 1. The statistic *d* has approximately a standard normal distribution under the null hypothesis that Pattern 1 is equally strong for the two groups. Large (bold) positive values of *d* relative to the Gaussian ($d > 2.00$) provide evidence that Pattern 1 is stronger in Group *I*. Conversely, large (bold) negative values give evidence that Pattern 1 is stronger in Group *II*.

Table 3b. Logistic regressions for every pair of questions answered by the groups in Table 1

	Pair of questions					
	(1, 2)	(3, 5)	(4, 6)	(7, 8)	(9, 10)	(11, 12)
Intercept	−1.8378 (0.0048)	1.0799 (<.0001)	0.3438 (0.1000)	–	–	2.9196 (0.0085)
Covariates						
gender	0.9824 (0.0414) [2.671]	–	–	–	–	–
age	–	–	–	–	–	–
marital status	–	–	–	–	−1.1429 (0.0736) [0.319]	–
parenthood	–	–	–	–	0.9885 (<.0001) [2.687]	–
handedness	–	–	–	–	–	–
negative life events	–	−1.1669 (0.0193) [0.311]	–	–	–	–
emotional state 1	–	–	–	–	–	–
emotional state 2	–	–	–	–	–	–
emotional state 3	–	–	–	–	–	−2.5348 (0.0191) [0.079]
emotional state 4	1.8613 (0.0020) [6.432]	–	–	–	–	–
emotional state 5	–	–	–	0.5913 (0.0083) [1.806]	–	–
affective circumplex 1	–	–	–	–	–	–
affective circumplex 2	–	–	–	–	–	−0.9646 (0.0369) [0.381]
religiousness	–	–	–	–	–	–

Note: In a logistic regression, the response variable assumes the value one for the answers AD and BC, and the value zero, otherwise. The covariates were selected by the stepwise method, and the coefficients were estimated by the maximum likelihood method. Values in parentheses are the *p*-values based on Wald chi-square statistics, and values in square brackets are the odds ratios. An odds ratio > 1 means a greater probability of violation of expected utility. "–" denotes that a covariate did not enter the model. The results, which show the contribution of a covariate for the probability of violation through either the answer AD or BC, are in accordance with those using the statistic *d* (Table 3b).

Table 4a. Answers given by the two groups for the pairs of questions where a biocharacteristic presents a significant statistic *d* in Table 3a

Biocharacteristic	Pair of questions	Statistic *d*	Group	Answer given, %			
				BC	AD	BD	AC
gender	(1, 2)	**–2.34**	*I*	26.5	12.2	53.1	8.2
			II	**49.2**	11.9	20.3	18.6
	(9, 10)	**–2.07**	*I*	51.0	5.9	27.4	15.7
			II	**68.9**	**6.6**	18.0	6.5
menstrual cycle	(4, 6)	**2.17**	*I*	**40.0**	**40.0**	10.0	10.0
			II	29.3	17.0	22.0	31.7
mother's age	(3, 5)	**–2.07**	*I*	40.9	4.5	27.3	27.3
			II	**51.9**	**22.2**	7.4	18.5
marital status	(9, 10)	**2.52**	*I*	**65.0**	6.0	20.0	9.0
			II	25.0	8.3	41.7	25.0
parenthood	(9, 10)	**–3.21**	*I*	11.1	11.1	44.4	33.4
			II	**65.7**	5.9	20.6	7.8
digit ratio	(4, 6)	**–2.03**	*I*	38.7	9.7	25.8	25.8
			II	**56.7**	**16.7**	10.0	16.6
	(7, 8)	**–2.25**	*I*	40.0	6.7	36.7	16.6
			II	**67.7**	6.5	16.1	9.7
negative life events	(3, 5)	**2.29**	*I*	**53.8**	**18.0**	11.5	16.7
			II	34.6	11.5	30.8	23.1
emotional state 2	(11, 12)	**–2.02**	*I*	30.4	6.5	30.5	32.6
			II	**40.6**	**15.6**	29.7	14.1
emotional state 3	(11, 12)	**4.57**	*I*	**54.5**	**36.4**	9.1	0.0
			II	34.3	9.1	32.3	24.3
emotional state 4	(1, 2)	**–2.88**	*I*	20.0	8.0	48.0	24.0
			II	**44.9**	**14.1**	29.5	11.5
emotional state 5	(7, 8)	**–2.04**	*I*	30.0	0.0	40.0	30.0
			II	**53.9**	**8.8**	28.5	8.8
affective circumplex 1	(11, 12)	**–2.31**	*I*	25.0	6.3	40.6	28.1
			II	**41.5**	**13.0**	26.0	19.5
affective circumplex 2	(11, 12)	**2.62**	*I*	**51.3**	**12.8**	23.1	12.8
			II	28.6	10.0	34.3	27.1

Note: Evidence of the Allais paradox is given by the answers AD and BC. Positive (negative) *d* values are related to Group *I* (Group *II*). Violation of expected utility theory by the answer BC is the commonest for every biocharacteristic (that is, violations are systematic), excluding "menstrual cycle."

Table 4b. Simple logistic regressions for the pairs of questions where a biocharacteristic presents a significant statistic *d* in Table 3a

Biocharacteristic	Pair of questions	Statistic *d*	Simple logistic regression		
			Estimated coefficient	*p*-value	Odds ratio
gender	(1, 2)	**–2.34**	0.9048	0.0225	2.471
	(9, 10)	**–2.07**	0.8443	0.0396	2.326
menstrual cycle	(4, 6)	**2.17**	–1.5329	0.0714	0.216
mother's age	(3, 5)	**–2.07**	1.2321	0.0445	3.429
marital status	(9, 10)	**2.52**	–1.5885	0.0147	0.204
parenthood	(9, 10)	**–3.21**	2.1759	0.0089	8.810
digit ratio	(4, 6)	**–2.03**	1.0761	0.0493	2.933
	(7, 8)	**–2.25**	1.1896	0.0305	3.286
negative life events	(3, 5)	**2.29**	–1.1669	0.0193	0.311
emotional state 2	(11, 12)	**–2.02**	0.7854	0.0473	2.193
emotional state 3	(11, 12)	**4.57**	–2.5667	0.0163	0.077
emotional state 4	(1, 2)	**–2.88**	1.3074	0.0091	3.696
emotional state 5	(7, 8)	**–2.04**	0.5913	0.0083	1.806
affective circumplex 1	(11, 12)	**–2.31**	0.9705	0.0291	2.639
affective circumplex 2	(11, 12)	**2.62**	–1.0451	0.0117	0.352

Note: The results for the simple logistic regressions are in accordance with those using the statistic *d* (Table 4a).

Table 5a. Answers given by the subjects with reference to their handedness and religiousness: Statistic *d*

Biocharacteristic	Pair of questions	Statistic *d*	Group	Answer given, %			
				BC	AD	BD	AC
handedness	(7, 8)	**1.67**	*I*	**53.8**	**8.5**	27.3	10.4
			II	40.0	0.0	40.0	20.0
religiousness	(3, 5)	**1.47**	*I*	**47.7**	**19.3**	13.7	19.3
			II	45.8	4.2	29.2	20.8

Note: The positive *d* values are related to Group *I*, that is, right-handers and theists (Table 1). Though the statistic *d* is not statistically significant in both cases ($d < 2.00$), there is a clear tendency for the subjects to give the answers AD and BC, the answer BC being the norm (that is, violations of expected utility theory are systematic).

Table 5b. Answers given by the subjects with reference to their handedness and religiousness: Simple logistic regression

Biocharacteristic	Pair of questions	Statistic *d*	Simple logistic regression		
			Estimated coefficient	*p*-value	Odds ratio
handedness	(7, 8)	**1.67**	–0.9062	0.1800	0.404
religiousness	(3, 5)	**1.47**	–0.7102	0.1283	0.492

Note: The positive *d* values are related to Group *I*, that is, right-handers and theists (Table 1). Similar to the statistic *d*, the estimated coefficients are not statistically significant in both cases; however, there is still a clear tendency for the subjects to give the answers AD and BC.