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Abstract

We conducted a questionnaire study with student subjects to look for explicit correlations between selected biological characteristics of the subjects and manifestation of the Allais paradox in the pattern of their choices between sets of two pairs of risky prospects. We find that particular bio-characteristics, such as gender, menstrual cycle, mother's age, parenthood, digit ratio, perceived negative life events, and emotional state, can be related to the paradox. Women, in particular if not menstruating, are less susceptible to the paradox. Those born to not-too-young mothers are also less prone to the paradox. The same holds true for those who father children, those with high prenatal testosterone exposure, who have reported many negative life events, and those who were anxious, excited, aroused, happy, active, and fresh at the time of the experiment. Further, left-handers and atheists may be less inclined to exhibit the paradox.

Keywords: Allais paradox, choice under risk, biological characteristics.

JEL classification: C91, D81

1. Introduction

Expected utility theory, the mainstream's economic theory of risky decision making, cannot accommodate the puzzle that ubiquitously emerges in questionnaires known as the Allais (1953) paradox. Consider the two pairs of situations (described in detail below): 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 preference of A over B should entail the preference of C over D, and conversely. However, people often violate that.

Allais himself explains the paradox by the expected utility theory's neglection of two basic psychological features: (1) the non-identity of monetary and psychological values, and (2) it does not suffice to consider only the mathematical expectation of utility; its distribution as a whole about its mean should also be taken into account (Allais, 2008). When very large sums are involved in comparison with the psychological capital of the subject, there is strong dependence between different gambles and probabilities. This can entail very strong risk aversion in the neighborhood of certainty, and preference for risk far from certainty.

Interestingly, Allais (2008) observed the utility curve derived from his experiments to bear similarity to the expression for psycho-physiological sensation as a function of luminous stimulus. This prompted us to perform deep research on the more general biological roots of the Allais paradox. Here, we investigate whether a subject's biological characteristic makes him or her more prone to display the paradox.

We apply the variants of the Allais example used by Kahneman and Tversky (1979) to 120 student subjects. We also apply a pre-questionnaire to gather information about a subject's gender and age, whether they father 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 "bio-characteristics" are related to the paradox.

The rest of this article is organized as follows: next, we provide a brief overview of the findings relating risk and bio-characteristics to justify our own characteristics selected in the pre-questionnaire; then, we explain the Allais paradox in detail, and the test statistics used; the content of the questionnaire is then described, that is, the questions for which the subjects responded, which are related to the Allais paradox; the subsequent section describes the data gathered from both questionnaires; finally, we present the results and a conclusion.

Attitudes toward risk and their relation to biological characteristics

The biological roots of decision making under risk do matter. Now, we provide a brief overview of findings to justify that. This allows us to conjecture that some biological characteristics of the subjects should also be considered for the Allais paradox. In what follows, we focus on our selected bio-characteristics, namely gender, age, parenthood, handedness, second-to-fourth digit ratio, current emotional state, perceived negative live events, and religiousness.

Gender

Differences in behavior between the sexes do exist and may reflect differences between the brains of males and females. Men have more gray matter (central bodies of nerve cells) and less white matter (filaments that connect nerve cells) than women do. That is why men rely more on gray matter for their IQ, whereas women rely more on white matter. Female brains seem to be hardwired for understanding emotions, and male brains for understanding and building systems. It has to be said, however, that the differences between the sexes tend to be exaggerated. Meta-analyses of several studies suggest that men are only slightly better than women in spatial ability and physical aggression, while women are slightly better in smiling, spelling, and indirect aggression; however, there is no significant difference in mathematical problem solving, vocabulary, and reading comprehension.

Gender differences may also be important for risk taking. If anything, women are more risk averse. Portfolios of single women are commonly less risky 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 this experimental evidence may be framing dependent. Men are also believed to be more overconfident than women. Because overconfidence leads to overtrading and lower returns, men appear to be less "rational" than women on 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 to expected utility theory through the Allais paradox.

We also find it worthwhile focusing on particular female characteristics such as 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 pre-questionnaire whether female subjects were either ovulating or menstruating. These bio-characteristics were then related to the pattern of violation to expected utility theory in the questionnaire. (Eckel and Grossman, 2008 provide an excellent survey on the relationship between the gender and the risk.)

Here, we find that gender does matter, and menstrual cycle, too. In our experiment, men are more prone to show the Allais paradox. Among the women, those who were menstruating at the time of the experiment were more predisposed to incur in the paradox in their choices of risky prospects.

Age

In the case of behavior, age is considered to be important. There is not much difference between a 25-year-old brain and a 75-year-old brain. However, hormonal factors trigger a need to impress peers by reckless behavior, and this inability to perceive risks accurately is high in the years between 10 and the mid-20s. Moreover, an urge for "sensation seeking" reaches a peak during the late teen years, and then declines gradually throughout life. Those who are higher in sensation seeking tend to have higher levels of testosterone than others. 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 this allows us to conjecture that people under 25 years of age show a pattern of behavior related to the Allais paradox that differs from that of older subjects.

We also conjecture that mother's age affects a boy's predisposition to the Allais paradox. Boys born to young mothers are at the high risk of committing crime 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. (For an overview that goes deeper by studying the neural basis of the relationship between the age and the risk taking, see Lee *et al.*, 2008.)

In this study, we find that boys born to young mothers (a variable measured by taking mother's age minus son's age ≤ 25 years) were less prone to exhibit the Allais paradox.

Parenthood

Growing kids alter 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-like substance that promotes bonding patterns) in the expectant mother, and this affects her brain to promote maternal behavior. Prolactin also promotes care-giving behavior and directs brain reorganization to favor maternal behavior. Live-in father's oxytocin levels also rise toward the end of his mate'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 father's testosterone level to protect his mate and child, but tempers his aggression, making him less capricious. Father's prolactin levels also rise after cohabitation with the child. Elevated prolactin levels in both the nursing mother and involved father cause some reduction in their testosterone levels, even though they also raise the pleasure hormones known as opioids. Fathers usually have lower salivary testosterone levels than unmarried men and married non-fathers. (On this subject, see 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. Here, we find that childless subjects are more prone to show the Allais paradox.

Handedness

Approximately 10 to 13 percent of any population is left-handed. However, no one knows the exact reason why the human population is right-hand dominant. Genetics certainly plays a role, but it is certainly not the only factor behind 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 remained constant over 30,000 years. This suggests that there exists an evolutionary role for left-handers, which have a “surprise” factor in combat, and also that the forces causing left-handedness are independent of culture.

Left-handed people occupy the extremes when it comes to health and ability. There are more left-handed people with IQs over 140 than right-handed people. Left-handedness has also been associated with talent in music and sports. This may partly be due to the fact that 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: left-handers are more prone to accidents. (See Raymond *et al.*, 1996 and references therein for a full coverage of left-handedness.)

All this allows us to conjecture that risky choices are made differently by left-handed people. Left-handers may also display a distinct pattern of violation to expected utility theory than that of right-handers. This study suggests that right-handers are more susceptible to the Allais paradox, though this result lacked a statistical significance in our sample.

Second-to-fourth digit ratio

Second-to-fourth digit ratio is a marker for prenatal testosterone exposure. Thanks to that, it may influence choice under risk. It may also be related to a subject's predisposition to the Allais paradox. 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) as compared to ring fingers (4D). Low digit ratios are caused by high prenatal testosterone exposure, low prenatal estrogens, or both. Low digit ratios 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. (Voracek and Loibl, 2009 provide a comprehensive survey of the digit ratio literature.)

We thus conjecture that low-digit ratio men make choices of risky prospects differently. Here, we find that their pattern of choice is indeed different. Men with relatively longer index fingers, that is, men with low prenatal testosterone exposure, are more likely to incur in the Allais paradox.

Emotions

Emotions surely play a role in one's attitude toward risk, though this is ignored by expected utility theory. An emotion refers to a collection of body states' changes triggered by the brain responding to specific contents of one's perceptions, actual or recalled, relative to a particular object or event. The "somatic marker hypothesis" proposes that decision making is influenced by emotion through marker signals that arise in bio-regulatory processes. Without this emotional signal, people rely on a reasoned cost–benefit analysis involving both immediate and future consequences. However, knowledge without emotional signaling leads to dissociation between what one knows or says, and how one decides to act. Sound and rational decision making depends on prior accurate emotional processing. Though rationality has its place, the survival value of emotions like fear, disgust, and joy is obvious: "run away from it; don't eat it; do more of it." Emotion can be beneficial to decision making when it is integral to a task, but it can also be disruptive when unrelated to the task.

The brain evolved to make emotional and rational decisions on the one hand, and controlled and automatic decisions on the other. Cost–benefit analysis only makes sense for controlled and rational decisions. People still evaluate the objective level of alternative risky choices as in the expected utility model, but they also react to risk emotionally. Risk-averse behavior may be governed by immediate responses to fear that occur in the amygdala. In risky choices, controlled and rational decisions can either cooperate or compete with automatic and emotional decisions. Fear can discourage people from taking advantageous gambles, but insufficient fear can produce non-maximizing behavior when risky options have 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.

On the face of it, we conjecture that emotional states are related to the pattern of choice between alternative risky prospects, and thus 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 apart from the characteristic "very anxious," all the others show relation with the manifestation of the Allais paradox. In particular, in the absence of emotions like anxiety and excitement, people are more inclined to show the paradox.

Images from functional magnetic resonance imaging show that different levels of risk activate different brain areas. Prefrontal damage disconnects the cognitive and affective systems, and damaged patients do not store the pain of remembered losses. In general, normal people who react more emotionally to negative life events tend to be more risk averse than average. For some people, negative life events and depression are related. Women report slightly more negative life events than men do. Despite that, women are not actually more vulnerable to negative life events than men are (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 incur in the Allais paradox. In our questionnaire, we asked subjects to report their perceived negative life events in a scale from 0 to 10 ranging from few negative events to many. We find that the subjects reporting few negative life events were more prone to manifest the Allais paradox.

We also track the emotions of the subjects using the model of the affective circumplex (Russell, 1980) (Figure 1) 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 above (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 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 matter for the occurrence of the Allais paradox. We find that not aroused, not excited, unhappy, quiet, and tired people are more prone to exhibit the paradox.

Religiousness

Though it sounds odd at first sight, religiousness can also be considered a biological trait. This is so because there is neurological and evolutionary basis for religious experience. "Neurotheology" studies the human urge for religious myth from a neurological point of view. The hard facts about the bio-characteristics of God-believers have been unearthed by neurotheology. There may be hormonal basis for God-believing, 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 explain why people vary greatly in spiritual zeal. The latter may also have a genetic basis. Serotonin and testosterone may be linked, too. When a high testosterone man is frustrated in his attempts to achieve dominance, serotonin comes into play. Low serotonin activity is associated with hyper-responsiveness to aversive stimuli, and thus results in a greater likelihood of an intensely negative emotional reaction. (Religiousness as a biological trait is discussed in

Joseph, 2002.)

From the discussion above, 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. Here, we find that God-believers are more susceptible to the Allais paradox, though this result lacked statistical significance.

Next section discusses the Allais paradox in more detail, along with the test statistics here employed to track it.

2. Materials and methods

The 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 the B and D answers and the A and C answers. Violations to the theory refer to the A and D answers, and the B and C answers. The fact that the violations in questionnaires are most of the B and C type, and not of the A and D type, suggests that they are systematic (Conlisk, 1989). Here, it is useful to identify two patterns of violations to expected utility theory.

Pattern 1. Violations by the AD and BC answers.

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

For testing pattern 1, two groups of subjects and the test statistic d are considered (Conlisk, 1989). The two groups considered in this study refers to the binary forms of our bio-characteristics, for example, male vs. female, subject aged 25 and below vs. 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 AD and BC answers, 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 (2) should refer separately to either group *I* or *II* when calculating d using (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 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 to 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 pre-questionnaire conveying information about the bio-characteristics of the subjects.

Questionnaire

The subjects were given the questions below, which draw on the questionnaire presented 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 in Question 1 and choose C in Question 2. Assuming the utility $u(\$0) = 0$, the choice of B in Question 1 means $.34u(\$2,400) > .33u(\$2,500)$. However, the choice of C in Question 2 implies the reverse inequality. This constitutes a violation to 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 both the domain of gains and the domain of 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 $u(\$3{,}000)/u(\$4{,}000) > 4/5$, 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 $.9u(\$3,000) > .45u(\$6,000)$. 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 and Tversky's questionnaire, most subjects choose A in Question 11, which implies $.45u(-\$6,000) > .90u(-\$3,000)$. However, they choose D in Question 12, which implies the reverse inequality.

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

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

Data

The previous questions were distributed to 120 subjects (62 males and 58 females) from the Federal University of Santa Catarina, Brazil. These were students from 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 pre-questionnaire asking for the respondents' bio-characteristics preceded the questionnaires. Table 1 shows the group description for every bio-characteristic.

3. Results

First, we tested for the occurrence of pattern 2 in the responses given to every pair of questions described above, that is, we assessed whether violations to expected utility theory in our experiment are significantly systematic. As observed, systematic violations mean that most answers are of the BC type rather than of the AD type.

Table 2 shows the results of the test statistic Z described by equation (3). As observed, positive values of Z indicate systematic violations, and large Z-values ($Z > 2.00$) relative to the Gaussian 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 to expected utility theory are systematic.

As for the role the subjects' bio-characteristics play, Table 3 shows the results for the test statistic d (described by equation (1)) for the pairs of questions by considering the subject groups in Table 1. As seen, the statistic d tracks the difference in the strength of pattern 1 (that is, violations to expected utility theory through the AD and BC answers) between the two groups I and II, as defined in Table 1. Large positive values of d ($d > 2.00$) relative to the Gaussian provide evidence that pattern 1 is stronger in group I. Conversely, large negative values give evidence that pattern 1 is stronger in group *II*. Values in bold in Table 3 show the significant cases. Apart from the bio-characteristics “handedness” and “religiousness,” all the rest are statistically significant in at least one pair of questions.

Table 3 shows that the subjects are more prone to exhibit the Allais paradox while choosing between the risky prospects depending on the following bio-characteristics: gender, menstrual cycle, mother’s age, parenthood, digit ratio, perceived negative life events, and emotional state. (Observe that though the bio-characteristic “age” is not significant, “mother’s age” 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 that reported few negative life events, and (7) subjects reporting an emotional state of lack of anxiety, excitement, arousal, and also those who were unhappy, quiet, and tired.

Table 4 shows the answers given by group for the pairs of questions where a bio-characteristic presents a significant *d* statistic in Table 3. As observed, evidence of the Allais paradox is given by the BC and AD answers. Positive (negative) *d* values are related to group *I* (group *II*). Violation to expected utility theory through the BC answer is the commonest for most bio-characteristics (that is, violations are systematic), apart from “menstrual cycle.” Also note that *d* is significant in both BC and AD types of answer for the pairs that are mirror images for losses, that is, the pairs (4, 6) and (11, 12).

Table 5 shows the answers given by the subjects by considering their handedness and religiousness. 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 BC and AD answers, being the BC answer the commonest (that is, violations to expected utility theory are systematic). (Intriguingly, no left-hander gave the AD answer.) The positive d values in Table 5 are related to group I, that is, right-handers and God-believers (Table 1). Thus, left-handers and atheists are less prone to display the Allais paradox. In our sample, 21 percent are made of atheists, and 9.2 percent are of left-handers. We speculate that a sample greater than 231 subjects will confirm the pattern shown in Table 5 with a $d > 2.00$.

5. Conclusion

We replicate the Allais example in the choice of alternative prospects in a sample of 120 student subjects. In addition, we show that the following bio-characteristics were closely related to the propensity of one subject to incur in the Allais paradox: gender, menstrual cycle, mother's age, parenthood, digit ratio, perceived negative life events, and emotional state. The Allais paradox is more likely 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 to have experienced few negative life events, and (7) subjects reporting an emotional state of lack of anxiety, emotion, excitement, arousal, and also those who were unhappy, quiet, and tired.

Right-handers and God-believers seem to be more susceptible to the Allais paradox, though this result is not statistically significant. However, we speculate that a larger sample will replicate this finding.

Put another way, our study suggests that women, in particular if not menstruating, are more "rational" in that they are less susceptible to the Allais paradox. Those born to not-too-young mothers are more rational, too. Those who father kids are also more rational. Those with high prenatal testosterone exposure are more rational.

Those with many negative life events are also more rational. Anxious, excited, alerted, happy, active, and fresh people are also more rational. Left-handers and atheists are possibly more rational, too.

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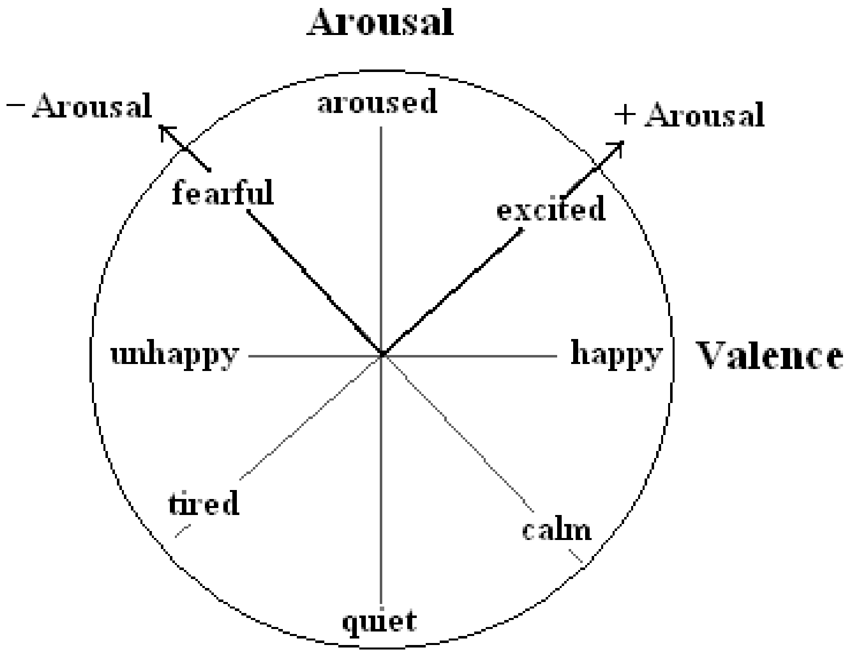

Figure 1. Affective circumplex: a graphical representation of the circumplex model of affect with the horizontal axis representing the valence dimension and the vertical axis representing the arousal or activation dimension.

Table 1. Group description for every bio-characteristic

Bio-characteristic	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	fathering 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	God-believer	atheist

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

Pair of questions	Systematic violations	Non-systematic 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 to expected utility theory are purely random. Positive values of Z indicate systematic violations, and large (in bold) Z-values (> 2.00) relative to the Gaussian provides evidence of pattern 2 (that is, most answers are of the BC type rather than of the AD type).

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

Bio-characteristic	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 to expected utility theory through the BC and AD answers) 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 (in bold) positive values of *d* ($d > 2.00$) relative to the Gaussian provide evidence that pattern 1 is stronger in group *I*. Conversely, large (in bold) negative values give evidence that pattern 1 is stronger in group *II*.

Table 4. Answers given by group for the pairs of questions where a bio-characteristic presents a significant *d* statistic in Table 3

Bio-characteristic	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 BC and AD answers. Positive (negative) *d* values are related to group *I* (group *II*). Violation to expected utility theory by the BC answer is the commonest for every bio-characteristic (that is, violations are systematic), apart from "menstrual cycle."

Table 5. Answers given by the subjects by considering their handedness and religiousness

Bio-characteristic	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 God-believers (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 BC and AD answers, being the BC answer the norm (that is, violations to expected utility theory are systematic).