The biological basis of expected utility anomalies

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Abstract

We assess the biological basis of expected utility anomalies through an experiment of the Allais paradox. A questionnaire study of 120 subjects replicates the anomalies and further gathers information about the respondents' bio-characteristics, such as gender, age, parenthood, handedness, second to fourth digit ratio, current emotional state, past negative experiences, and religiousness. We find that some of those bio-characteristics matter for the anomalies.

Keywords: expected utility anomalies, risky choice, Allais paradox, experimental economics

JEL classification: C91, D81

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1. Introduction

Expected utility theory (Von Neumann and Morgenstern, 1944; Savage, 1954) is a benchmark in the analysis of risky decision making. Yet there are several classes of choice problems that systematically violate the theory's axioms in questionnaires. Those problems are mainly related to Allais (1953) paradox. A number of generalizations to expected utility theory have been proposed to cope with such anomalies, but a common criticism is that none of these models consistently organize data (Battaglio et al., 1990).

Rather than proposing another alternative theory, this paper will change perspective and go back to Allais paradox in order to investigate the biological reasons why people departs from expected utility theory. The insights gained in this line of research can be useful for extra fruitful generalizations of expected utility theory. By applying the questionnaire in Kahneman and Tversky (1979), which is made up of versions of the Allais paradox, we will replicate the paradox and further consider the biological characteristics of the respondents. We will find that the bio-characteristics matter for the anomalies.

The rest of the paper is organized as follows. Section 2 will survey the previous literature on the bio-characteristics selected in our pre-questionnaire. Section 3 will present the expected utility anomalies considered in our questionnaire. Section 4 will describe data from the questionnaires. Section 5 will perform analysis. And Section 6 will sum up and conclude.

2. Bio-characteristics

The anomalies to expected utility theory may have biological basis. Here we will review the literature on selected characteristics, such as gender, age, parenthood, handedness, second to fourth digit ratio, current emotional state, perceived lifetime negative experiences, and religiousness. Our aim is to make the case that those bio-characteristics underlie risky choice primarily because of the brain and hormones.

Gender

Female is the default brain setting. The human body becomes male as a result of surges of testosterone, one during gestation and one shortly after birth. Differences in behavior between the sexes may reflect differences between the brains of males and females. Men have more grey matter (central bodies of nerve cells) and less white matter (filaments that connect nerve cells) than women. Thus men rely more on grey matter for their IQ, whereas women rely more on white matter. Baron-Cohen (2002) suggests that from birth, female brains are hardwired for understanding emotions (empathizing) and male brains for understanding and building systems (systemizing). Yet the differences between the sexes tend to be exaggerated. Hyde (2005) conducted a meta-analysis of a number of studies and found that men are slightly better than women in spatial ability and physical aggression; women are slightly better in smiling, spelling, and indirect aggression; and there is no significant difference in mathematical problem solving, vocabulary, and reading comprehension.

Gender differences may matter for risk-taking (Byrnes et al., 1999). If anything, women are more risk-averse. Portfolios of single women were found less risky than those of single men (Jianakoplos and Bernasek, 1998; Sunden and Surette, 1998), women may be more risk-averse toward gambles (Hershey and Schoemaker, 1980; Powell and Ansic, 1997), and relatively more pessimistic and insensitive to probabilities and, thus, more risk-averse (Fehr-Duda et al., 2006). However, such women's risk aversion seems to be framing dependent (Schubert et al., 2000). As for rationality, women are less prone to the cognitive illusion known as the 'disposition effect', according to which investors hold on to their losing stocks to a greater extent than they hold on to their winning stocks (Da Costa Jr et al., 2007), and this may be related to the fact that male and female brains interpret changing reference points differently (Baron-Cohen, 2002).

Men are more overconfident than women (Lundeberg et al., 1994; Barber and Odean, 2001). Men spend more time and money on security analysis, rely less on their brokers, make more transactions, believe that returns are more highly predictable, and anticipate higher possible returns than do women (Lewellen et al., 1977). But overconfidence leads to overtrading and lower returns (Barber and Odean, 2001). In this respect, women seem again to be more rational than men.

One particular bio-characteristic related to gender is women's menstrual cycle. Unlike in other female primates there is no clear advertisement of fertility within women's ovulatory cycle (Dixson, 1998). Yet ovulation cannot be completely concealed. Indeed women dress to impress near ovulation (Haselton et al., 2007). Follicular phase images are more attractive to men (Roberts et al., 2004), and women's body scents near ovulation are judged as more attractive by men (Doty et al., 1975; Singh and Bronstad, 2001; Thornhill et al., 2003). Women's sexual desires vary across the cycle (Bullivant et al., 2004; Gangestad et al., 2002; Haselton and Gangestad, 2006). On high fertility days of the cycle women report an increased desire to go to clubs and parties where they might meet men (Haselton and Gangestad, 2006). Women also increase attentiveness to 'maleness' at high fertility (Macrae et al., 2002), and prefer masculine facial features near ovulation (Gangestad et al., 2005). Women's attraction to and flirtation with men other than their primary partner is highest near ovulation (Bullivant et al., 2004, Gangestad et al., 2002; Haselton and Gangestad, 2006). And women are more intrasexually competitive near ovulation (Fisher, 2004). In short, women's sexual motivations increase near ovulation. We thus conjecture that this may interfere with their decision making under risk. Eckel and Grossman (2007) provide a recent survey on gender and risk.

In line with such studies, we will show below that male subjects tended to violate expected utility theory more than females, thus being less rational. Yet relatively older men were more rational. And anxious men tended to be less rational. But we will find no role for menstrual cycle in our sample.

Age

There is not much difference between a 25-year-old brain and a 75-year-old brain. Yet a combination of hormonal factors, an inability to perceive risks accurately, and the need to impress peers lead to reckless behavior in the years between 10 and the mid-20s (Goleman, 1987; Zuckerman, 1994). The biggest killers of young people are essentially psychological, i.e. their own lethal propensity for risk taking. What seems a clear danger in the eyes of an adult may seem safe enough to a teenager. The latter's perception of some risks may fade in face of peer pressure. When it comes to using condoms, their major concerns are not the risks of pregnancy, but rather whether they think their peers use condoms. The risk that matters most is in social rejection from not doing what peers do. By age 10 or so their cognitive development has not yet reached the point where they can make sensible judgments. They cannot comprehend laws of probability, have silly ideas of invulnerability, and are prone to exaggeration. When adopting imitative behavior they overestimate the actual numbers. And they also underestimate the safety of the dangerous things they do.

The urge for 'sensation seeking' reaches a peak during the late teen years and then declines gradually throughout life. There are four sub-dimensions to the sensation seeking trait (Zuckerman, 1994), namely (1) 'thrill and adventure seeking', which relates to a willingness to take physical risks and participate in high risk sports (in particular, the relationship between this trait and speed is the leading cause of car accident deaths for people up to the age of 39), (2) 'experience seeking', which relates to a need for new and exciting experiences, and is associated with all types of risk taking, (3) 'disinhibition', which relates to a willingness to take social risks and engage in health risk behaviors, such as excessive drinking or unprotected sex, and (4) 'boredom susceptibility', which relates to an intolerance for monotony and a need for sensory and social stimulation, such as loud music or parties.

Those who are highest in sensation seeking tend to have higher levels of testosterone than others (Zuckerman, 1994). 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 (Raine and Buchsbaum, 1996).

Mother age matters for children's future behavior. Thus one may conjecture that mother age affects one's attitude toward risk. Children born to young mothers are at highest risk for committing crime in adolescence (Comanor and Phillips, 2002). Maternal rejection, erratic or harsh behavior on the part of parents, and lack of parental supervision are among the best predictors of juvenile delinquency (Sampson and Laub, 1993). Birth complications combined with early maternal rejection predispose boys to violent crime at age 18 (Raine et al., 1994). Women who inadvertently become pregnant tend to smoke, drink, or using drugs, and this increases the chances of future criminality of their offspring (Raine et al., 1996). Having a teenage mother roughly doubles a child's propensity to commit crime (Rasanen et al., 1999).

Since teenagers and unmarried women are more likely to seek abortions (Levine et al., 1996), Donohue and Levitt (2001) linked the legalization of abortion in the early 1970s in the US to the drop in crime rates in the 1990s. Though this work is subject to criticism (Foote and Goetz, 2005), there is also evidence of the link for both Canada and Australia.

As for expected utility theory, the findings in this work are in line with the discussion above. We will find below that young subjects tended to violate more expected utility theory, thus being less rational. Yet will find no role for mother age in our sample.

Parenthood

Growing kids is expected to alter behavior (and perhaps, indirectly, one's attitude toward risk) because neural and hormonal interactions are involved in nurturing babies (Palmer, 2002). Hormones regulate the body's systems and help them to react to the environment. Nature controls brain organization and hormonal releases to best adapt the body to its environment through pheromones, which are steroid hormones made in our skin.

Estrogen triggers an increase of oxytocin (a hormone-like substance that promotes bonding patterns) in the expecting mother, and this affects her brain to promote maternal behaviors as well as to allow milk to flow. Changes in mother's nerve junctions make the maternal behaviors brain-wired. Mother's brain no longer signals her to adorn herself to get a mate; her grooming habits are directed toward baby. Oxytocin is also increased in the baby, deriving feelings of calmness and pain reduction along with mom. Live-in father's oxytocin levels also rise toward the end of his mate's pregnancy. Oxytocin in mother, father, or baby also promotes lower blood pressure and reduces risk of heart disease.

Vasopressin (known as the 'monogamy hormone') also plays a role in the father by promoting brain reorganization toward paternal and family bonding behaviors. While 'testosterone wants to prowl, vasopressin wants to stay home' (Crenshaw, 1996). Fathers have lower salivary testosterone levels than unmarried men and married non-fathers (Gray et al., 2006). Yet vasopressin reinforces father's testosterone to protect his mate and child, but tempers his aggression, making him less capricious.

Another hormone, prolactin, promotes caregiving behaviors and, over time, directs brain reorganization to favor maternal behaviors. Father's prolactin levels also rise after cohabitation with child. In children and non-parents, prolactin surges are related to stress levels, so it is generally considered a stress hormone. In parents, it serves as a parenting hormone. Elevated prolactin levels in both the nursing mother and involved father cause some reduction in their testosterone levels.

Opioids (pleasure hormones) are natural morphine-like chemicals created in our bodies. Opioids are released in child's brain as a conditioned response to parents' warm hugs and kisses; it helps reduce pain from a tumble or disappointment. The opioid system is stimulated by prolactin.

Breastfeeding causes dopamine and its product, norepinephrine (adrenaline), to be produced. These enhance energy and alertness along with some of the pleasure of attachment. Norepinephrine also helps organize child's stress control system.

Our study will find no role for parenthood in the violations of expected utility theory, however.

Handedness

Approximately 10 to 13 (or 30) percent of any population is left-handed. People who can use both hands equally are rare. No one knows for certain why the human population is right handed dominant, but a number of theories have been proposed. Genetics certainly plays a role, but it is not the only factor behind lefthandedness. 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 lefthanders remained constant over 30,000 years. This suggests an evolutionary advantage for lefthanders, which have a 'surprise' factor in combat, and also that the forces that cause right and lefthandedness are independent of culture. In primitive societies with highest levels of violence, lefthanders thrived (Faurie and Raymond, 2004).

A number of characteristics have been associated with lefthandedness. 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 (Searleman et al., 1984). Leftandedness has also been associated with musical talent (Hassler and Gupta, 1993). The high proportion of lefthanders among sportspeople may be partly due to the fact that lefthanders have an intrinsic neurological advantage over righthanders (Wood and Aggleton, 1989). Lefthanders seem to be predisposed to visual-based thought (Bradgon and Gamon, 2000). Males are three times more likely to be left handed than females. And homosexuals may be up to 39 percent as likely to be left handed as heterosexuals (Lindesay, 1987; McCormick et al., 1990; Lalumiere et al., 2000). Lefthandedness has also been linked to epilepsy (Schachter et al., 1995), Down's syndrome (Batheja and McManus, 1985), autism (Cornish and McManus, 1996), and mental retardation (Grouios et al., 1999). Left handed peoples' lifespans 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; indeed, lefthanders are more prone to accidents (Coren, 1996).

Lefthandedness may be linked with testosterone (Geschwind, 1984; Moffat and Hampson, 1996). This suggests that hormones may also play a role. The male brain matures later than that of the female, and the left hemisphere matures later than the right. Testosterone suppresses the growth of the left hemisphere and so more neurons migrate to the right hemisphere. The highly developed right hemisphere is now better suited to function as the center of language and handedness. The fetus is more likely to become left handed, since the right hemisphere controls the left half of the body.

Lefthandedness also appears to occur more frequently in identical twins if compared to the general population (Cantor et al., 2005). One twin of a pair has a 20 percent chance to be left handed. It has been hypothesized for a long time that left handed individuals may be the survivors of 'mirror image' identical twinning (Newman, 1928), though recent research does not seem to support that view (Medland et al., 2003). However recent use of ultrasound has uncovered the phenomenon of the 'vanishing twins'. A vanishing twin is a fetus that dies in the womb and is then reabsorbed by the mother. One in eight single births began as a twin pregnancy (Landy et al., 1986). And the surviving twin may be a fratricide. Thus it sounds reasonable to conjecture that risky choices are made differently by left-handed people. We will show below that lefthanders tended to violate less expected utility theory in our sample.

Second to fourth digit ratio

High testosterone levels are correlated with social dominance in many species. 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), i.e. men have relatively shorter index fingers (2D) compared to ring fingers (4D) (Manning, 2002). Low digit ratios are caused by high prenatal testosterone levels, low prenatal estrogens, or both (Cattrall et al., 2005; Csatho et al., 2003; Lutchmaya et al., 2004; Manning, 2002; Manning et al., 1998; Van Anders et al., 2006; Williams et al., 2003). Low digit ratios are associated with high sperm numbers (Manning et al., 1998), good health (Manning, 2002), great number of sexual partners (Honekopp et al., 2006b), great number of children fathered (Manning et al., 2000), superior athletic and musical ability (Sluming and Manning, 2000; Manning and Taylor, 2001; Honekopp et al., 2006a), and high levels of courtship behavior in the presence of potential mates (Roney and Maestripieri, 2004).

Since testosterone and aggression are related, it is not so surprising that low male ratio 2D:4D is related to physical aggression (Bailey and Hurd, 2005). Low female ratio 2D:4D, in turn, is related to reactive aggression (Benderlioglu and Nelson, 2004). Testosterone may also be related to increased fairness considerations. High testosterone males are more likely to reject unfair distributions (Burnham, 2003).

High testosterone may also affect economic decisions. An increase in testosterone levels after exposure to potential mates was associated with high likelihood of accepting small offers (Roney et al., 2003; Wilson and Daly, 2004). In an ultimatum-game experiment, low-digit-ratio high-testosterone men tended to lose their drive for a good deal after viewing sexy pictures (Van Den Bergh and Dewitte, 2006). A similar experiment was repeated with salivary testosterone (Burnham, 2007).

Thus here we conjecture that the second to fourth digit ratio (prenatal testosterone) influences (male) choice under risk. Indeed we will show below that men with low 2D:4D digit ratio were more likely to be caught violating expected utility theory.

Emotions

Emotion refers to a collection of body (‘somatic’) states’ changes triggered by the brain that responds to ‘specific contents of one’s perceptions, actual or recalled, relative to a particular object or event’ (Damasio, 1994; 1999; 2003). Emotions may play a role in one’s attitude toward risk. This can be inferred from new insights coming from neuroscience. Brain’s frontal lobes are linked to judgment, decision making, social conduct, and personality (Ackerly and Benton, 1948; Brickner, 1932; Welt, 1888; Eslinger and Damasio, 1985). People with bilateral damage to the ventromedial prefrontal cortex develop severe impairments in personal and social decision making, and in emotion and feeling; yet they have normal intellect (Bechara et al., 1998; Damasio et al., 1990; Eslinger and Damasio, 1985). The ‘somatic marker hypothesis’ is a neuroanatomical and cognitive framework for the decision making influenced by emotion (Bechara and Damasio, 2005; Damasio, 1994; Damasio et al., 1991). Such influence occurs through marker signals that arise in bioregulatory processes. Without this emotional signal, people rely on a reasoned cost-benefit analysis involving both immediate and future consequences. Yet 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. So emotion can be beneficial to decision making when it is integral to the task. However it can also be disruptive when unrelated to the task.

The brain is also designed for making automatic decisions (Bargh et al., 1996; Bargh and Chartrand, 1999; Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977).

'Neuroeconomics' is underpinned by a neural model of decision making that considers both emotion and reason on one hand, and controlled and automatic decisions on the other (Camerer et al., 2005). Homo economicus always employs some type of cost-benefit analysis (Loewenstein et al., 2001), and thus only makes sense for controlled-rational decisions. Yet risky choices should also consider the pairs of decision that are at the same time controlled-emotional, automatic-rational, and automatic-emotional. People still evaluate the objective level of alternative risky choices as in the expected utility model; but they also react to risk emotionally (Loewenstein et al., 2001). Risk-averse behavior may be governed by immediate responses to fear. And fear occurs in the amygdala (Phan et al., 2002). In risky choices, controlled-rational decisions can either cooperate or compete with automatic-emotional decisions (Loewenstein et al., 2001). Fear can discourage people from taking advantageous gambles (Gneezy and Potters, 1997). Yet insufficient fear can produce nonmaximizing behavior when risky options have negative expected value (Bechara et al., 1997). Sadness makes people prone to choose gambles of high-risk payoff. By contrast, anxiety tends to make people prone to choose gambles with low-risk payoffs (Raghunathan and Pham, 1999). Pathological gamblers tend to be male and also tend to drink, smoke, and use other drugs above average. The D2A1 gene allele is more likely to be present in pathological gamblers (Comings, 1998). Yet antidepressant 'naltrexone' reduces both the urge to gamble (Moreyra et al., 2000) and 'compulsive shopping' (McElroy et al., 1991).

Risky behavior in experiments has been increasingly monitored by brain scanning through fMRI (functional magnetic resonance imaging), which tracks blood flow in the brain using changes in magnetic properties due to blood oxygenation. Images from fMRI show that different levels of risk activate different brain areas (McCabe et al., 2001; Rustichini et al., 2005). Prefrontal damage disconnects the cognitive and affective systems, and damaged patients do not store the pain of remembered losses (Bechara et al., 1997). In general, normal people who react more emotionally to negative events tend to be more risk-averse than average (Peters and Slovic, 2000).

We will show below that self-reported anxious men were less rational in our sample in that they were more likely to violate expected utility theory.

Religiousness

Though it sounds odd at first sight, religiousness can be considered a biological trait. This is so because there is neural basis for religious experience (Ramachandran et al., 1998). 'Neurotheology' (Joseph, 2002) studies the human urge for religion and religious myth from a neurological point of view. It is thus implied that one cannot separate god from the believer. The hard facts about the bio-characteristics of god believers have been unearthed by neurotheology. There is hormonal basis for god-believing, too. Borg et al. (2003) employed PET (positron emission tomography) and found a relationship between low serotonin levels and self-transcendence for male subjects, a personality trait covering religious behavior and attitudes. They suggested that 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 have a genetic basis (Hamer, 2004). And serotonin and testosterone may be linked (Birger et al., 2003). 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. Thus we will conjecture that religiousness interferes with both behavior and one's attitude toward risk.

Participation in prayer enhances the immune system, lowers heart rate and restricts the release of stress hormones into the bloodstream (Newberg et al., 2001). Providing assistance for those troubled by the existential dilemma, religious beliefs played an important role as human societies developed. Providing contexts for a moral code, religion encouraged bonding within groups, bolstering the group's chances of survival. So the human brain may hold an 'evolutionary advantage' with its capacity to believe in god. Or religion itself did not offer any advantage in evolutionary terms; rather, it is just a byproduct of other cognitive capacities we evolved, which did have advantages (Boyer, 2002). Believing in god cannot at first be dismissed as irrational and religious behavior can even affect positively economic activity (Iannaccone, 1998). However, religion arguably caused more hate and suffering in history than any other single cause. Dawkins (2006) makes a case against religion and observes that the Old Testament's god is 'a misogynistic, homophobic, racist, infanticidal, genocidal, filicidal, pestilential, megalomaniacal, sado-masochistic, capriciously malevolent bully'.

To investigate the relationship between brain function and spiritual experience, Newberg et al. (2001) injected a radioactive tracer into the arms of Tibetan monks and Franciscan nuns in deep meditation and prayer. Images from SPECT (single photon emission computerized tomography) showed an increase in neuronal activity within the prefrontal cortex as well as low activity in the parietal lobe. The prefrontal cortex is the area of the brain associated with attention and concentration whereas the parietal lobe is the area related to time concept and spatial orientation. As sensory information getting into the parietal lobe is blocked, it keeps trying to give a sense of self, but it no longer has the information to do so. With limited neuronal activity, the parietal lobe is unable to distinguish the boundary between the external world and the physical self. This explains both the 'sense of oneness' with the universe and the 'mingling with god' reported by the subjects.

Within the frontal cortex there is an area (dubbed the 'god spot') that becomes hyper sensitive during moments of deep religious reflection. It corresponds to Eastern religions' 'third eye'. To enhance personal spiritual awareness, some ancient religious sects used to cut a small hole into the skull around this area. If not a god spot, we may have specialized circuits for belief (Ramachandran et al., 1998). Religious belief may be brain-wired. Thus we may also conjecture that atheists possibly have a differently configured neural circuitry.

Penfield (1975) conducted a series of experimental operations (during the 1950s) on patients who suffered seizures within the frontal cortex and temporal lobe areas. Using only local anesthetic, he asked patients to describe their feelings as he accessed different areas. By touching the temporal lobe usually produced feelings of paranormal, spiritual presence, and consciousness of the meaning of the whole cosmos. The clinical impression from surgeons is that patients with right hemispheric temporal lobe lesions tend to increase their religiousness (Beaumont et al., 1999). In particular, the development of epilepsy in the temporal lobe and limbic hyper-activation often causes a patient to obsess over religion (Joseph, 2001; Ramachandran et al., 1998; Newberg et al., 2001). Seizures in the temporal lobe strengthen certain neural pathways connected to the amygdala, and sufferers tend to attribute significance to banal objects and occurrences.

Persinger (1993) designed a 'god helmet' that causes a temporary influx of neuronal firing in the limbic system, much like as occurs during natural temporal lobe epilepsy. He observed that subjects usually experience a sense of timelessness, paranormal visions, and even report to come 'face to face' with god. In the presence of neuronal imbalance in the left hemisphere of the temporal cortex (the area related to the sense of self), the brain interprets the presence of the right hemisphere as a personified 'other entity', or god (Persinger and Healey, 2002).

Predisposition may play a role in one's experience during temporal lobe seizure, i.e. sufferer's experiences follow expectations based on their personal beliefs. So a Christian is more likely to 'encounter' god at a seizure than a non-believer. Atheist Richard Dawkins wore the god helmet and reported only to experience mild limb pain and slight respiratory difficulties.

The so-called Broca's area of the brain (responsible for speech and language recognition) remains active during meditation and epileptic seizure. By restricting sensory information causes the Broca to misjudge the internal voice as one generated by external stimuli. This misinterpretation can lead people to confuse their internal monologue with the voice of an external entity. This explains why some claim to hear the 'voice of god'.

The presence of spiritual, godlike beings can also be experienced after combining sensory and social isolation with the taking of LSD (Lilly, 1972). This explains why Shamanistic tradition and Native American rituals incorporated drugs such as mescaline, peyote and psilocybin to achieve heightened spiritual sensation (Schultes et al., 2002). Intense sensory stimulation, such as dancing or chanting, also arouses the limbic system and heightens 'religious experience'.

Perception may also play a role. Neuronal activity cannot always discriminate between real events and those that one perceives to be real. Although spiritual experience can be traced through neuronal activity, it does not necessarily mean that those experiences are due to 'neurological illusion' alone (Newberg et al., 2001). There is little difference between how the brain processes the experiential, either real or supposed. The difference lies within how one perceives experience.

We will find below that self-reported (female) atheists were more rational in the sense that they violate less expected utility theory.

3. Expected utility anomalies

Whereas our pre-questionnaire collected information about the subjects' bio-characteristics as described in the previous section, our questionnaire reproduced the expected utility anomalies that are versions of Allais (1954) paradox as described by Kahneman and Tversky (1979). The Allais paradox is accommodated neatly by prospect theory; and both paradox and theory are likely to be brain wired (Trepel et al., 2005). A number of generalized expected utility models have been developed to account for the expected utility anomalies, such as rank-dependent utility theory (Quiggin, 1982), weighted utility (Chew and MacCrimmon, 1979), and the generalized smooth preferences model (Machina, 1982), among many others that have proliferated. Yet the most frequently used model is cumulative prospect theory (Kahneman and Tversky, 1992), which is an update of prospect theory.

Questions 1 and 2 are variants of the Allais paradox.

Question 1
Choose between

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

Question 2
Choose between

A	B
\$2,500 with probability 33%	\$2,400 with probability 34%
\$0 with probability 67%	\$0 with probability 66%

Most people usually choose B in Question 1 and choose A in Question 2. Assuming $u(\$0)=0$, the choice of B in Question 1 means $.34u(\$2,400) > .33u(\$2,500)$. Yet the choice of A in Question 2 implies the reverse inequality.

Questions 3–6 show more variants of the same phenomenon.

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

A	B
\$4,000 with probability 20%	\$3,000 with probability 25%

Question 6
Choose between

A	B
A loss of \$4,000 with probability 20%	A loss of \$3,000 with probability 25%

Subjects usually choose B in Question 3 and A in Question 5. The choice of B in Question 3 implies $u(\$3,000)/u(\$4,000) > 4/5$ whereas the choice of A in Question 5 implies the reverse inequality. However subjects usually choose A in Question 4, and B 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. This also suggests a psychological propensity to overweight certainty that favors risk aversion in the domain of gains and risk seeking in the domain of losses.

Questions 7 and 8 are versions of the Allais paradox 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

A	B
A three-week tour of England, France, and Italy with probability 5%	A one-week tour of England with probability 10%

Subjects usually choose B in Question 7 but choose A in Question 8.

Questions 9 and 10 refer to situations where winning is possible but not probable, and most people choose the gamble that offers the largest gain. Questions 11 and 12 show 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

A	B
\$6,000 with probability 0.1%	\$3,000 with probability 0.2%

Subjects usually choose B in Question 9, which implies $.9u(\$3,000) > .45u(\$6,000)$. But choose A in Question 10, which implies the reverse inequality.

Question 11
Choose between

A	B
A loss of \$3,000 with probability 90%	A loss of \$6,000 with probability 45%

Question 12
Choose between

A	B
A loss of \$3,000 with probability 0.2%	A loss of \$6,000 with probability 0.1%

Subjects usually choose B in Question 11, which implies $.45u(-\$6,000) > .90u(-\$3,000)$. But choose A in Question 12, which implies the reverse inequality.

Question 13 shows how preferences may be altered by different representations of probabilities (Tversky, 1972).

Question 13
In a two-stage game, you go through the second stage with probability 25%.
If you reach the second stage, choose between

A	B
\$4,000 with probability 80%	\$3,000 with certainty

Subjects usually choose B in Question 13. The gambles in Question 13 are similar to those in Question 5 because A has a $.25 \times .80 = .20$ chance, and B has a $.25 \times 1 = .25$ chance. But in Question 5 subjects usually choose A. Here subjects tend to neglect the game's first stage and incorrectly consider Question 13 similar to Question 3.

Questions 14 and 15 show how preferences may be altered by varying the representation of outcomes. They also show the phenomenon of risk aversion for positive gambles and risk seeking for negative ones.

Question 14
In addition to whatever you own, you have been given \$1,000.
You are now asked to choose between

A	B
\$1,000 with probability 50%	\$500 with certainty

Question 15
In addition to whatever you own, you have been given \$2,000.
You are now asked to choose between

A	B
A loss of \$1,000 with probability 50%	A loss of \$500 with certainty

Subjects usually choose B in Question 14, and choose A in Question 15, although all the gambles have the same expected value, i.e. $\$1,500$.

4. Data

Questionnaires containing 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. A pre-questionnaire to track the respondents' bio-characteristics preceded the questionnaires.

The pre-questionnaire gathered information about gender, menstrual cycle, age, mother age, marital status, parenthood, handedness, digit ratio, perceived degree of past lifetime negative experiences, emotional state (Andrade and Iyer, 2007), current status in the affective circumplex as shown in Figure 1 (Watson et al., 1999), and religiousness (Table 1).

5. Analysis

We defined p_k as the probability of a subject to answer k^{th} question so as to violate expected utility theory, i.e. $p_k = P(X_k = 1)$, where X_k is a binary random variable that takes on the value of one if a subject violates expected utility theory, and of zero otherwise. Table 2 shows piece of evidence supportive of the anomalies in the sample. Only the answers to Questions 2 and 15 were not statistically significant, i.e. violation occurred by chance ($p_k = \frac{1}{2}$). Overall our experiment replicated the expected utility anomalies.

We reckoned an index of average violation for every subject as

$$V = \frac{X_1 + X_2 + ... + X_{15}}{r},$$

where $r \in [1,\ 15]$ is one subject's number of valid answers; thus $r = 15$ if he or she answered all the questions. In the sample, 99 subjects answered all the questions, 18 answered within the range $10 \le r \le 14$, and only 3 subjects answered 5 or 6 questions. Quantity r was found linearly correlated with gender, i.e. $r = 14 + 0.85 \times \text{gender}$ ($p < 0.007$, two-sided *t*-test). Figures 2 and 3 show that the index of average violation depended on two particular biological characteristics, namely gender and handedness. For all the valid questions, the average of V was 0.65 ± 0.03 (95 percent significant). This figure indicates how much on average the subjects tended to violate expected utility theory, i.e. $\sim 65\%$. The index V was found linearly correlated with gender ($V = 0.62 + 0.06 \times \text{gender}$), i.e. male subjects tended to violate 6 percent more than females. Although this may be provoked by greater exposure of males regarding the violations (i.e. as V was regressed on gender, r, and $r \times \text{gender}$, only r remained in the model, 5 percent significant), a *d* statistic to be presented below will confirm that males tended to violate more. On average, each valid response raised index V by 2 percent, i.e. $V = 0.35 + 0.02 \times r$.

The index V was then fitted to one subject's biological profile B. Since in our data $0 < V < 1$, we performed a logit transformation of the dependent variable. Thus $\text{logit} = \ln[V/(1-V)]$. For the index of average violation we adjusted model $\ln[V/(1-V)] = \beta B$, where β is a parameter vector whose dimension depends on the number of bio-characteristics selected *B*, i.e. those statistically relevant for the answers given. By employing the Bayesian information criterion to select the explanatory variables we found that

$$\ln \frac{V}{1-V} = 1.350 + 0.284 \times \text{gender} - 0.495 \times \text{handedness} - 0.034 \times \text{age}$$

($p \leq 0.053$, two-sided *t*-test). On average, females, lefthanders, and older subjects tended to violate expected utility theory less, i.e. they were more 'rational', i.e.

$$V = \frac{\exp(1.350 + 0.284 \times \text{gender} - 0.495 \times \text{handedness} - 0.034 \times \text{age})}{1 + \exp(1.350 + 0.284 \times \text{gender} - 0.495 \times \text{handedness} - 0.034 \times \text{age})}.$$

By considering the values in Table 1 and the equation above, a 20-year-old boy that is also right-handed, for instance, has a 72 percent chance of violating expected utility theory, whereas a 40-year-old right-handed man has a 57 percent chance.

We found it interesting to apply the logit model for boys and girls separately. For boys, we adjusted model $\ln[V_1/(1-V_1)] = \beta B$ and got the male index of average violation V_1, where the bio-characteristics mother age and digit ratio were included in B. We found

$$\ln\frac{V_1}{1-V_1} = 43.597 - 4.929 \times \text{2D} + 4.846 \times \text{4D} - 41.388 \times \text{2D:4D}$$
$$+0.384 \times (\text{emotional state 1 or 2}) - 0.042 \times \text{age}$$

($p \leq 0.027$, two-sided *t*-test). Thus boys with high prenatal testosterone (low digit ratios) were more likely to violate expected utility theory, and self-reported anxious men were less rational. The female index of average violation V_2 was similarly found by adjusting model $\ln[V_2/(1-V_2)] = \beta B$, where B now includes menstrual cycle. We found

$$\ln\frac{V_2}{1-V_2} = 0.52 \times \text{religiousness}$$

($p \leq 0.001$, two-sided *t*-test). Thus god believers were more likely to violate expected utility theory.

That gender matters for the anomalies to expected utility theory can also be seen with the help of the *d* statistic, which is defined by the means' difference, $\overline{X}_1 - \overline{X}_2$, divided by the joint standard deviation, assuming that both groups are homogeneous (Cohen, 1988). Inhomogeneity would mean an artificially big d. The d statistic makes sense here because (as seen in Section 2) men and women are different, but not too much different. So

$$d = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\dfrac{n_1 S_1^2 + n_2 S_2^2}{n_1 + n_2}}}.$$

It can be rewritten for proportions as

$$d = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\dfrac{n_1\overline{X}_1(1-\overline{X}_1) + n_2\overline{X}_2(1-\overline{X}_2)}{n_1 + n_2}}}.$$

Table 3 shows that the d statistic for the index of average violation of each sex has a positive value. This confirms that female subjects tended to violate less expected utility theory than males. Table 8 shows the statistics for the individual questions.

6. Summary and conclusion

Since neural processes mediate risk-taking behavior, the biological (neural and hormonal) characteristics of subjects may matter for their decisions under risk. In particular, the observed expected utility anomalies of the Allais paradox may have neural basis and their biological roots may be uncovered if one explicitly takes the bio-characteristics of subjects into account.

To assess this, we distributed questionnaires containing versions of the Allais paradox to 120 subjects only to find the anomalies replicated. We also distributed pre-questionnaires aimed at tracking the subjects' bio-characteristics. The latter gathered information about gender, menstrual cycle, age, mother age, marital status, parenthood, handedness, digit ratio, perceived degree of past lifetime negative experiences, emotional state, current status in the affective circumplex, and religiousness. By employing the Bayesian information criterion to select explanatory variables, we found that some of those bio-characteristics do underlie the anomalies.

A logit model allowed us to find that on average 65 percent of the subjects tended to violate expected utility theory. Male subjects tended to violate 6 percent more than females. A d test confirmed that females were more 'rational', in the sense that they violated expected utility theory less. Older women were even more rational. Self-reported anxious men were less rational. Males with high prenatal testosterone (i.e. with low 2D:4D digit ratios) were less rational. Young subjects (men and women) were found less rational, too. Finally, self-reported female atheists were even more rational.

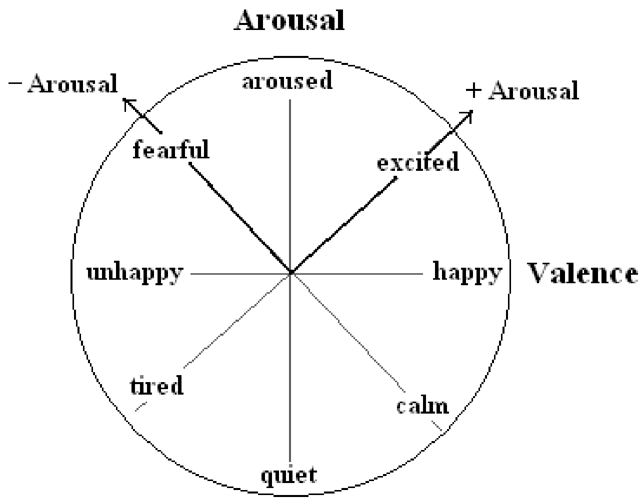

Figure 1. Affective Circumplex (Watson et al., 1999).

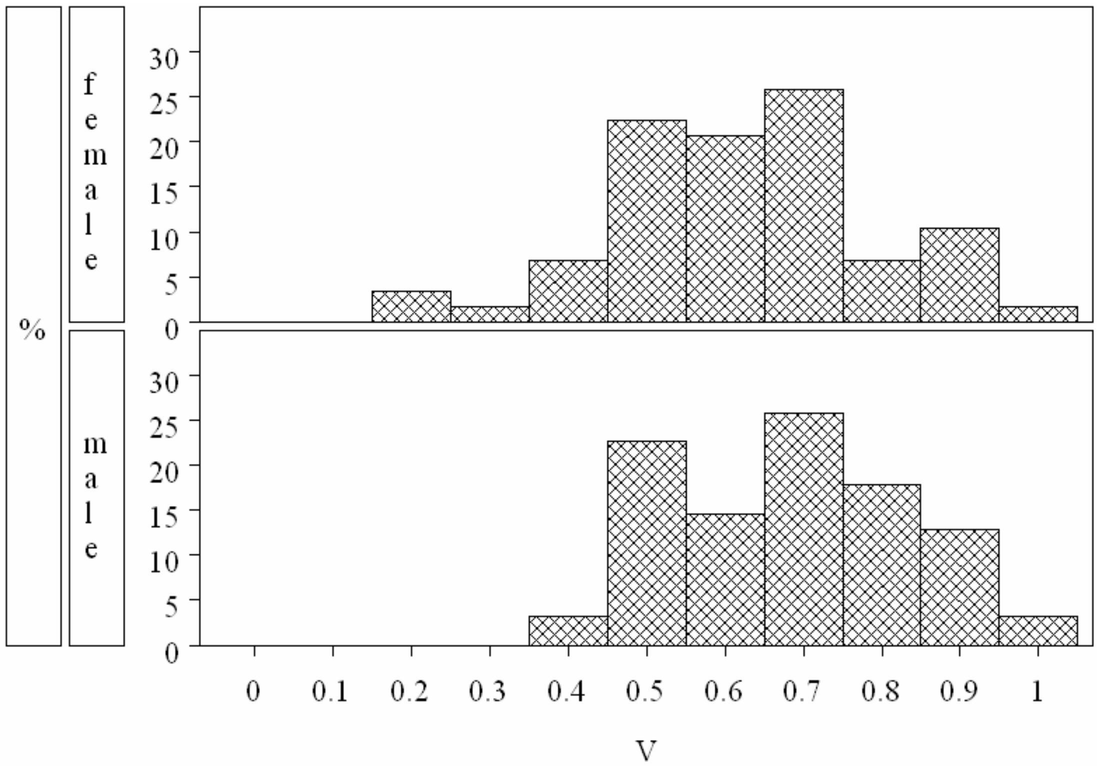

Figure 2. Distribution of the index of average violation V by gender

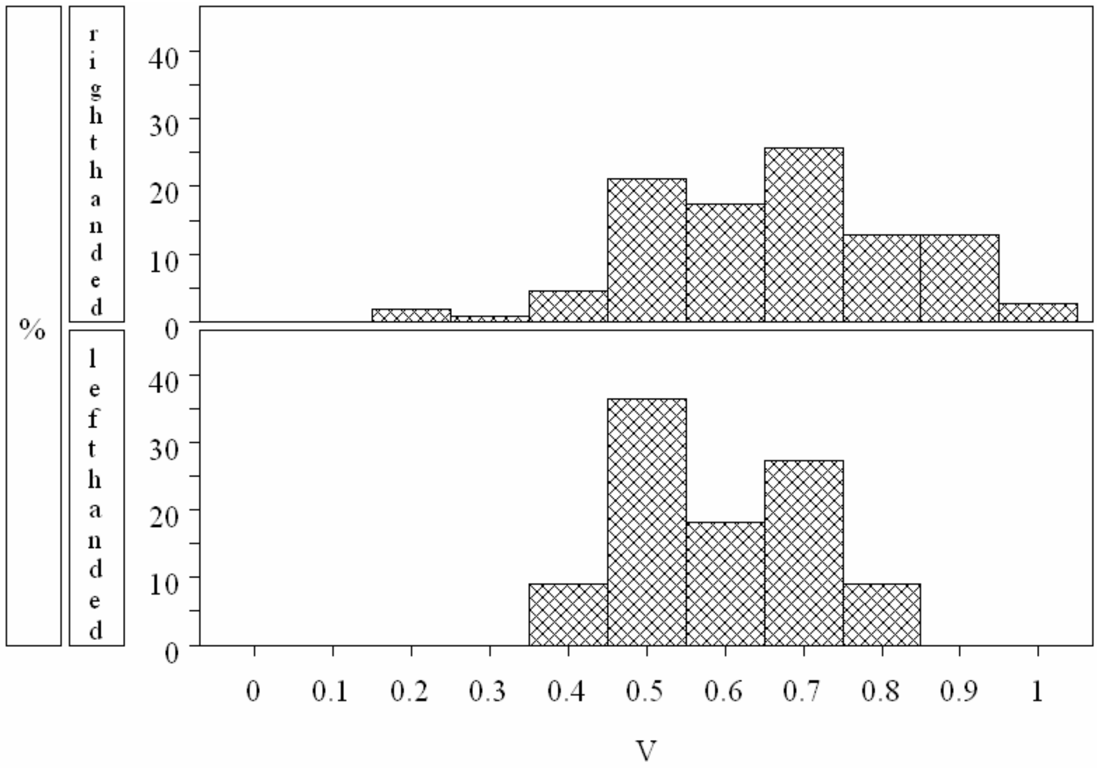

Figure 3. Distribution of the index of average violation V by handedness

Table 1. Bio-characteristics

variable	category	value
gender	male	1
	female	0
ovulating?	yes	1
	no	0
age		18–49
mother age		41–71
marital status	single	1
	other	0
children?	yes	1
	no	0
handedness	lefthander	1
	righthander	0
digit ratio	2D:4D < 1	1
	other	0
past negative experiences		0–10
emotional state 1	very anxious	1
	other	0
emotional state 2	moderately anxious	1
	other	0
emotional state 3	emotionless	1
	other	0
emotional state 4	moderately excited	1
	other	0
emotional state 5	very excited	1
	other	0
affective circumplex status		1–8
god believer?	yes	1
	no	0

Table 2. Expected utility violation: estimates without considering the bio-characteristics

question k	sample size n	number of violations	p_k estimate	z ratio* of hypothesis test $H_0 : p_k = \frac{1}{2}$	significance level
1	110	81	0.736	4.96	0.00000
2	*113*	*57*	*0.504*	*0.09*	*0.92505*
3	116	75	0.647	3.16	0.00160
4	113	72	0.637	2.92	0.00354
5	113	76	0.673	3.67	0.00024
6	115	68	0.591	1.96	0.05020
7	118	96	0.814	6.81	0.00000
8	117	75	0.641	3.05	0.00228
9	115	94	0.817	6.81	0.00000
10	114	82	0.719	4.68	0.00000
11	115	77	0.670	3.64	0.00028
12	115	67	0.583	1.77	0.07643
13	119	82	0.689	4.13	0.00004
14	120	86	0.717	4.75	0.00000
15	*120*	*51*	*0.425*	*–1.64*	*0.10035*

Note

* $z = \dfrac{p_k - 0.5}{0.5/\sqrt{n}}$

Table 3. d statistic for the index of average violation of both sexes

male			female			
sample n_1	V_1	S_1^2	sample n_2	V_2	S_2^2	d
62	0.681	0.02262	58	0.623	0.02881	0.36

Table 4. d statistic for the individual questions k

k	male			female			d
	sample size n_1	number of violations	$\overline{X}_1$	sample size n_2	number of violations	$\overline{X}_2$	
1	60	41	0.6833	50	40	0.8000	−0.26
2	61	40	0.6557	52	17	0.3269	0.66
3	62	39	0.6290	54	36	0.6667	−0.08
4	61	42	0.6935	52	30	0.5769	0.23
5	62	43	0.6885	51	33	0.6471	0.10
6	61	40	0.6557	54	28	0.5185	0.28
7	61	49	0.8033	57	47	0.8246	−0.05
8	61	41	0.6721	56	34	0.6071	0.14
9	61	53	0.8689	54	41	0.7593	0.28
10	61	46	0.7541	53	36	0.6792	0.17
11	62	43	0.6935	53	34	0.6415	0.11
12	62	39	0.6290	53	28	0.5283	0.20
13	62	36	0.5806	57	46	0.8070	−0.49
14	62	50	0.8065	58	36	0.6207	0.41
15	62	27	0.4355	58	24	0.4138	0.04

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