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Moreira, Bruno; Matsushita, Raul and Da Silva, Sergio

Federal University of Santa Catarina

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Bruno Moreira

Federal University of Santa Catarina, Graduate Program in Economics, 88049970 Florianopolis SC, Brazil
E-mail address: brunocmmoreira@gmail.com
Tel/Fax: +55 48 3721 9901

Raul Matsushita

University of Brasilia, Department of Statistics, 70910900 Brasilia DF, Brazil
E-mail address: raulmta@unb.br

Sergio Da Silva

Federal University of Santa Catarina, Graduate Program in Economics, 88049970 Florianopolis SC, Brazil
E-mail address: professorsergiodasilva@gmail.com
Tel/Fax: +55 48 3721 9901
Corresponding author

Abstract

A recent neurobiology study showed that monkeys systematically prefer risky targets in a visual gambling task. We set a similar experiment with preschool children to assess their attitudes toward risk and found the children, like the monkeys, to be risk seeking. This suggests that adult humans are not born risk averse, but become risk averse. Our experiment also suggests that this behavioral change may be due to learning from negative experiences in their risky choices. We also showed that though emotional states and predetermined prenatal testosterone can influence children's preferences toward risk, these factors could not override learning experiences.

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PsycINFO classification: 2300

Keywords: Risk; Children

1. Introduction

Both people and animals typically avoid choosing the risky option when confronted with two options of the same mean value but differing in uncertainty (Rode et al., 1999; Bateson, 2002). The decision to take a particular action depends on subjective preferences and objective rewards. In axiomatic microeconomic theory, preferences are represented by utility and an optimal choice is made by maximization of utility. The utility of a choice with uncertain outcomes is its expected utility, and is determined by summing the utility of each possible outcome weighted by its probability (Bernoulli, 1738; Von Neumann and Morgenstern, 1944). Risk preference implies a particular shape for the utility function. The inverse relationship between risk and expected utility should be logarithmic rather than linear (Bernoulli, 1738). This should be consistent with the fact that a small amount of money means a larger increase in utility to the poor than to the rich. Thus, the representation of preferences over gambles by the utility function embodies the property of risk aversion and implies a concave shape for the function (Jehle and Reny, 2001).

Several anomalies of the expected utility theory have been well documented in experimental economics, the most important being the Allais paradox (Allais, 1953). As a result, a number of generalizations have been proposed (Tversky and Kahneman, 1992). The most prominent theoretical alternative is the prospect theory (Kahneman and Tversky, 1979). This psychological approach posits that what influences risk attitudes is not the expected outcome of a choice but the distinct reactions to gains and losses; expected utility theory is right (and people are really risk averse) only for gains. Cumulative prospect theory (Tversky and Kahneman, 1992) updates prospect theory to consider high- and low probabilities. People are risk averse for gains of high probability but also for losses of low probability, and are risk seeking for losses of high probability but also for gains of low probability. Such developments justify why the same person can show distinct attitudes toward risk, such as insuring a car used to drive to the casino. The anomalies (Camerer et al., 2005) and prospect theory itself (Trepel et al., 2005) seem to be tuned to the functioning of the brain.

Not only psychology but also neurobiology can further contribute to our understanding of decision-making involving risk (Platt and Huettel, 2008). In terms of the brain processes involved, expected utility theory (and for that matter all rational-choice models of optimization) implicitly assumes that behavior is the result of decisions that are both controlled and rational, and thus they occur in the cerebral cortex

(Camerer et al., 2005). However, decisions can also be spontaneous (Schneider and Shiffrin, 1977; Bargh et al., 1996) and emotional (Zajonc, 1980; Panksepp, 1998; Damasio, 1995; Davidson and Irwin, 1999; Bechara and Damasio, 2005). Attitudes toward risk can be controlled and rational but are also automatic and emotional (Loewenstein et al., 2001). The neural basis explaining why the same person can show both risk-aversion and risk-seeking tendencies depending on the circumstances may be explained by the fact that controlled-, rational-, automatic-, and emotional brain processes may either cooperate or compete (Camerer et al., 2005). Immediate fear responses to risks and fear itself occur in the amygdala (Vuilleumier et al., 2001; Brand et al., 2007). The amygdala also receives inputs from the cortical brain, and both the amygdala and orbital prefrontal cortex act as part of an integrated neural system guiding decision-making (Baxter et al., 2000). The amygdala and orbitofrontal cortex are critical for a variety of food-motivated behaviors in animals (Gallagher, 2000) and humans (Hamann et al., 1999). The amygdala also plays a role in learning processes that involve an emotional component, but the prefrontal cortex has the potential to regulate such affective processes through inhibition of the lateral nucleus of the amygdala. In particular, the medial prefrontal cortex (infralimbic- and prelimbic cortices) regulates affective behaviors that are mediated by the basolateral amygdala complex (lateral-, basal-, and accessory basal nuclei) (Rosenkranz et al., 2003). The medial prefrontal cortex inhibits conditioned fear by gating impulse transmission from the basolateral amygdala to the central nucleus of the amygdala (Quirk et al., 2003). The anterior cingulate cortex is activated in the detection of conflict between rational responses and effects associated with the emotional amygdala-based system (Botvinick et al., 2001).

The other limbic area of particular interest in our study is the posterior cingulate cortex, which is also involved in risky decision-making (McCoy and Platt, 2005). The posterior cingulate cortex translates subjective valuation signals into choice by making connections with brain areas implicated in processing reward, attention, and action (Vogt et al., 1992). This area is activated by the likelihood of rewards that are uncertain in either amount (Smith et al., 2002) or time (Kable and Glimcher, 2007). Neurons in the posterior cingulate cortex physiologically respond to visual stimuli (Dean et al., 2004) after visual-orienting movements (Dean et al., 2004; Olson et al., 1996) and rewards (McCoy et al., 2003). Thus, the posterior cingulate cortex contributes to decision-making by evaluating external events and actions with respect to the subjective psychological state (utility) (Olson et al., 1996; McCoy et al., 2003).

108   Individual neurons in the posterior cingulate cortex of monkeys were shown to

109   respond according to the riskiness of choice (McCoy and Platt, 2005). In a gambling

110   task to assess whether neuronal activity in that brain area reflects subjective utility or

111   objective available rewards, two adult male rhesus macaques were trained to choose

112   between two options on a computer screen by indicating their choice with an eye

113   movement. Turning their gaze to a certain target delivered a fixed amount of 150-ms

114   access to fruit juice as reward. However, the amount of juice available from the other

115   target was uncertain. Turning their gaze to the risky target resulted in the random receipt

116   of less than 150 ms in one half of the trials, and more than 150 ms in the other half of

117   the trials (mean = 150 ms). Thus, choosing the risky target had a 50:50 chance of

118   receiving a reward larger or smaller than the mean. No other differences between the

119   targets were involved so that only the riskiness of choice differentiated the two. Risk

120   was systematically manipulated by changing the difference between the smaller reward

121   and the larger reward available from the risky target. Both monkeys systematically

122   preferred the risky target, and the riskier the target, the more likely they were to choose

123   it. The animals continued to favor the risky option even in a second, less safe

124   experiment when the probability of obtaining a larger reward from the risky target was

125   reduced so that the risky choice led to a smaller average reward. The activity of

126   individual neurons in the posterior cingulate cortex was recorded and was shown to

127   respond more strongly after making risky choices. More than half of the neurons

128   signaled not only the choice but also the riskiness of the choice made. Neurons

129   responding more strongly to the risky target signaled its utility rather than merely the

130   size of the expected reward, because the responses correlated with preference for the

131   risky option rather than with the objective value of the option. The utility of the risky

132   target was greater than the utility of the average reward, and the animals were thus

133   found to be risk prone.

134   We set a similar experiment with preschool children using real fruit juice but,

135   obviously, we did not record neuronal activity. The experiment was conducted with 100

136   genetically unrelated Brazilian children (48 little girls and 52 little boys) between the

137   ages of 4 and 6. The children were offered the choice between a visible quantity of 150

138   ml of strawberry juice and a random receipt of 0 ml or 300 ml of juice. The experiment

139   was performed prior to school snack time and repeated after the snack time. It aimed at

140   tracking possible reinforcement learning (Sutton and Barto, 1998), which occurs when a

141   system (biological or artificial) receives new information and then updates its belief

142   about the environment in proportion to its prediction error, and which is obtained from

143   the difference between the expected- and actual outcomes. The prediction error is then

144   multiplied by the learning rate to determine the degree by which the action value is

145   updated. If recent experience is more predictive of the future than distant experience (as

146   in our experiment) the learning rate should be large. When humans adjust their learning

147   rate in a Bayesian fashion, the anterior cingulate cortex shows activation (Behrens et al.,

148   2007).

149   Deviations from the predictions of axiomatic choice theory can sometimes be

150   explained by emotion, as proposed by disappointment (Bell, 1985) and regret theory

151   (Bell, 1982). Thus, our experiment also considered the possible influence of emotions in

152   children's decisions. Decision-making can be influenced by emotions through marker

153   signals that arise in bioregulatory processes (Damasio, 1995; Bechara and Damasio,

154   2005). Without these signals, people rely only on a reasoned cost-benefit analysis

155   involving both immediate- and future consequences. Yet rational decision-making

156   depends on prior accurate emotional processing. An emotional state can be beneficial to

157   decision-making when it is integral to a task, but it can also be disruptive when

158   unrelated to the task. One common way to depict emotional states is the affective

159   circumplex (Watson et al., 1999), where the states are represented in the circular flow:

160   aroused→excited→happy→calm→quiet→tired→unhappy→fearful→aroused.

161   We also considered the 2D:4D digit ratio of the children participating in our

162   experiment. High prenatal testosterone levels, low prenatal estrogens, or both cause low

163   digit ratios (Manning, 2002). Males tend to have relatively shorter index fingers (2D) if

164   compared to ring fingers (4D). Thus, males have lower values of the 2D:4D ratio

165   (~0.98) than females (~1). Both prenatal- (Van Den Bergh and Dewitte, 2006) and

166   salivary (Apicella et al., 2008) testosterone have been related to risk preferences. Risk

167   preferences may be partly predetermined if prenatal testosterone plays a decisive role.

168

169   **2. Results**

170   *2.1 Children's characteristics*

171   The reason why we decided to perform the experiment with children aged

172   between 4 and 6 was that they already consider themselves autonomous individuals

173   separated from their mothers, capable of dealing with quantities and counting, and of

174   realizing that events may have a cause. In addition, preschool children should have

175 relatively less of negative experiences in their past choices involving risk than older
176 children.

177   Schoolteachers freely reported the emotional state of the children during the
178 experiment, and we translated it in terms of the affective circumplex (Watson et al.,
179 1999) as follows: As for the little boys, 15.38 percent were reported as being aroused,
180 23.08 percent as happy, 28.85 percent as calm, 15.38 percent as quiet, and 17.31 percent
181 as fearful. The little girls were reported as happy (18.75 percent), calm (54.17 percent),
182 quiet (14.58 percent), and fearful (12.5 percent).

183   As expected (Manning, 2002), boys had an average 2D:4D ratio of 0.973
184 (standard deviation = 0.015), while girls had an average rate of 0.989 (standard
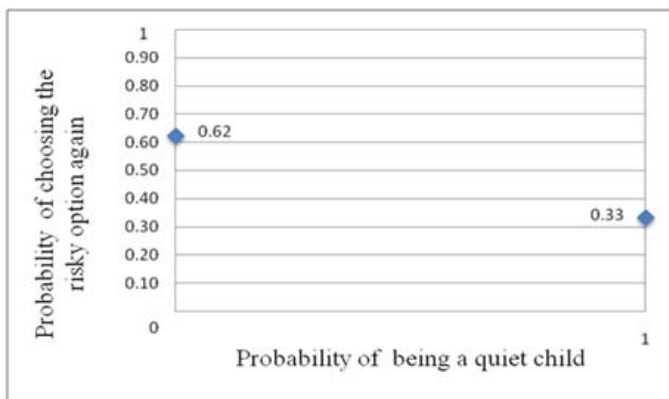185 deviation = 0.015).

186

187 *2.2 Experiment*

188   By setting the value 0 to the null hypothesis of risk aversion and the value 1 to
189 the alternative of risk seeking, we could not accept the null of risk aversion (mean = 0.8
190 prior to snack time, mean 0.69 after snack time, two-sided *t*-test < 0.0001, *n* = 100).
191 Repetition of the trial after school snack time aimed at tracking reinforcement learning
192 (as observed). Here we devised a positive learning variable related to the occurrences
193 where the previous choice of the risky option confirmed one child's expectation. A
194 negative learning variable was also conceived to capture the occurrences where the
195 previous choice of the risky option frustrated a child's expectation.

196   We hypothesized that negative learning ℓ^- calls for a change in the previous
197 risky choice, while positive learning ℓ^+ induces repetition of the risky option choice.
198 We found that negative learning influenced children's choice of the risky option by
199 making them more risk averse in the second trial (logistic regression, *p* < 0.0001, *z* =
200 5.8078, *n* =100). Subjects that experienced negative learning ($P(\ell^-)=1$) were more
201 likely to abandon the risky option chosen in the first trial than those that did not
202 experience negative learning ($P(\ell^-)=0$). Children experiencing negative learning had
203 a 22 percent chance of choosing the risky option in the second trial, while those that did
204 not experience negative learning had a 95 percent chance of choosing the risky option in
205 the second trial (Figure 1).
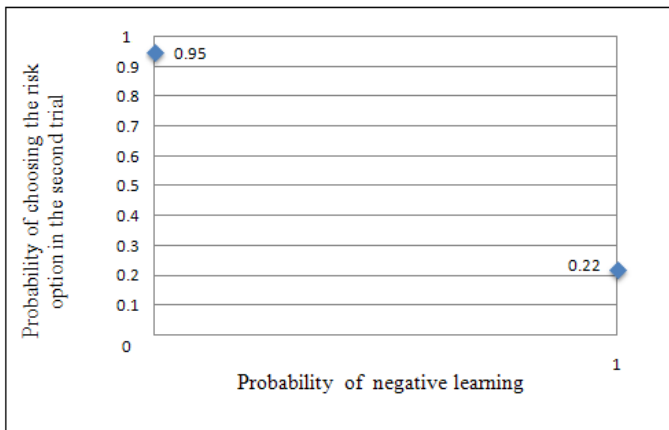
Figure 1. Children that had their expectations frustrated in the first choice of a risky option were less likely to choose the risky option in the second choice. Those experiencing negative learning ($P(\ell^-)=1$) had a 22 percent chance of choosing the risky option in the second trial, while those that did not experience negative learning ($P(\ell^-)=0$) had a 95 percent chance of choosing the risky option in the second trial.

We sought to know whether any of the variables considered were systematically related to the above behavior of choosing or not choosing the risky option in the second trial. We found that only 33 percent of the children reported as quiet, q, continued to choose the risky option again ($P(q)=1$) ($p = < 0.0430$, $z = -2.024$, $n = 100$). Thus, quiet children were more susceptible to (negative) reinforcement learning and were more likely to become risk averse in the second trial. Children with any other reported emotional state ($P(q)=0$) were, in contrast, 62 percent more likely to repeat the choice of the risky option in the second trial (Figure 2).

Figure 2. Quiet children ($P(q)=1$) were only 33 percent as likely to repeat the choice of the risky option in the second trial. In contrast, the others (aroused-, happy-, calm-, and fearful children) ($P(q)=0$) were 62 percent as likely to choose the risky option again in the second trial.

227   We also found the 2D:4D ratio to be related to the choices made by the children
228   in the first trial ($p = 0.0151$, $z = -0.4294$, $n = 100$). Subjects with smaller ratios (higher
229   prenatal testosterone) were more likely (98.65 percent chance) of being risk seeking in
230   the first trial. Subjects with a ratio approaching one were found to be only 66.5 percent
231   as likely of being risk seeking in the first trial (Figure 3). However, the digit ratio was
232   not statistically significant in the second trial. This interesting finding suggests that
233   hormones may even have predetermined a subject's choice but such a condition could
234   not overcome learning.
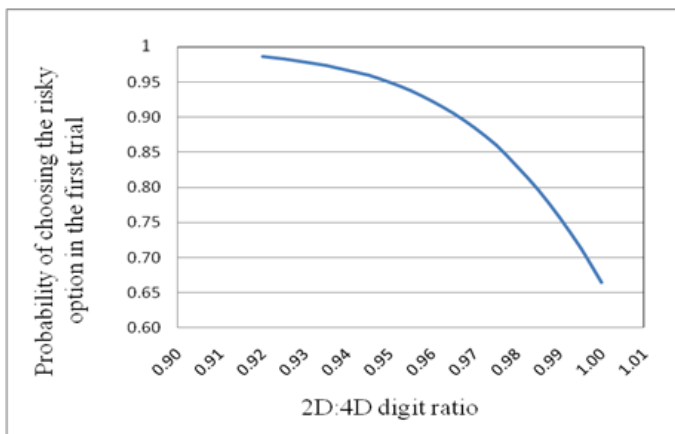
235
236   Figure 3. Children with higher prenatal testosterone were more likely to seek risk in the
237   first trial. Subjects with smaller 2D:4D digit ratios were 98.65 percent as likely of being
238   risk prone, whereas subjects with a ratio approaching one were found to be only 66.5
239   percent as likely of being risk prone in the first trial. However, prenatal testosterone did
240   not matter in the second trial.
241
242
243   **3. Methods summary**
244   *3.1 Questionnaire*
245   The Ethical Committee for Research with Human Beings of the Federal
246   University of Santa Catarina approved all procedures. Following the Committee's
247   instructions, we sent to parents a questionnaire informing them of the detailed
248   procedures of the experiment and seeking permission for their children to participate.
249   Children from Florianopolis, Brazil, were sampled from six schools. Of the 212 parents
250   that we approached, 47 percent consented and so predetermined the total number of 100
251   subjects who participated in the study.
252   The questionnaire asked for the level of education of parents. In the sample, 59
253   percent of mothers and 52 percent of fathers had a bachelor university degree or above.
254   The questionnaire also sought information about the mother's age. Prior to the
255   experiment, we conjectured that the mother's age could matter in children's attitude
256   toward risk because of the evidence that having a teenage mother roughly doubles a

257 child's propensity to commit crime in the future (Rasanen et al., 1999). However, we

258 did not find any role for that characteristic in our sample. We also collected information

259 about children handedness by observing their activities using their hands (mainly for

260 writing). Approximately 10–13 percent of any population is left-handed, and this

261 proportion has remained constant over 30 000 years, thus suggesting an evolutionary

262 role for lefthanders. A number of characteristics have been associated with left-

263 handedness. One of particular interest in our study was that lefthanders seemed to be

264 predisposed to visual-based thought (Bradgon and Gamon, 2000). Thus, we first

265 conjectured that in a visual gambling task children's handedness could play a role. As

266 expected, 11 percent of the children in the sample were left-handed. However, we did

267 not find any role for left-handedness in our experiment.

268   We also asked teachers to describe the children's emotional state during the

269 experiment. They returned free descriptions of emotional characteristics, and we

270 expressed them in terms of the affective circumplex (Watson et al., 1999) (as observed).

271 As for the children's fingers, we measured them directly with either a caliper or a rule,

272 and then calculated the digit ratios.

273

274 *3.2 Experiment procedures*

275   Our children's experiment differed from the monkey experiment in terms of

276 sample size and composition as well as the number of trials conducted. While the

277 monkey study employed two individuals and several trials, our experiment considered

278 100 subjects and only two trials. Since we sought to examine the influence of additional

279 characteristics such as emotional state, digit ratio, parents' level of education, mother's

280 age, and handedness in children's risk attitudes, a larger sample was needed to apply our

281 chosen statistical techniques. As for the number of trials, the monkey study found that

282 only the last five trials were significant for choice, and that the last trial was the most

283 important one. Thanks to this finding, and because we expected a high learning rate for

284 children (as observed), we confined our experiment to two trials.

285   In our study, a child participated in the first trial alone, and then left to the

286 playground without having contact with those still waiting to take part in the

287 experiment. The teachers told us that children did not communicate with one another

288 about the experiment because they were more interested in enjoying their snack time

289 rather than playing with classmates. This ensured that the second-trial choices that took

290 place soon after the end of snack time were based on the subjects' own preferences, and
291 thus we could rule out imitative behavior.

292   Two 30-cm^2 boxes were placed at two opposite corners of a large table. Prior to
293 the first trial, children were shown a transparent cylindrical glass (height = 15 cm) half-
294 full with 150 ml of strawberry juice that was placed inside the left-hand side box, and
295 were told that that box would remain open. They were then shown two glasses, one
296 empty, and the other filled with 300 ml of juice. Children were explained that only one
297 of the glasses would appear if they chose the right-hand side box that was kept closed.
298 Finally, they were told one more time that if they chose the open box they would
299 certainly receive a half-full glass, and if they chose the closed box they would receive
300 either an empty glass or a full glass. This reminder was to ensure that the child had
301 understood the task clearly. Flipping a coin determined whether it was an empty or a
302 full glass that would be hidden. In the course of the trial, the full glass appeared 53
303 times and empty glass 47 times.

304

305 *3.3 Analysis*

306   We analyzed data using the logistic regression

307

308     $$\text{logit}\,\pi_{ij} = \log\frac{\pi_{ij}}{1-\pi_{ij}} = \beta\mathbf{x}_{ij} \tag{1}$$

309

310 where $\mathbf{x}_{ij} = (x_{1j},...,x_{pj})$ is the vector of binary explanatory variables influencing the
311 risky choice π_{ij} over the two trials $j = 1, 2$. For data from the second trial of the
312 experiment, we regressed π_{i2} against positive learning ℓ^+, negative learning ℓ^-, satiety,
313 and the other remaining information gathered in the questionnaires. We defined
314 $\pi_{i2} = P(\text{trial}_2) = 1$ for risk-seeking subjects in the second trial, and $\pi_{i2} = P(\text{trial}_2) = 0$
315 for risk-averse subjects in the second trial. Vector $\mathbf{x}_{ij} = \mathbf{0}$ was defined for positive
316 learning, females, lefthanders, parents with level of education below university degree,
317 and quiet children, q; $\mathbf{x}_{ij} = \mathbf{1}$ for the corresponding opposite variables. Model
318 estimation and variable selection were run using SAS 9.1.

319   Stepwise-, backward-, and forward procedures ensured estimation of a
320 parsimonious model where ℓ^- was found to be the more relevant explanatory variable.

321 From the 22 children that switched preferences (from risk propensity to risk aversion),

322 18 had negative reinforcement learning. The model estimated then became

323

324 $$\text{logit}\,\pi_{i2} = 1.791 - 3.689\,\ell^- \tag{2}$$

325

326 or

327

328 $$\pi_{i2} = \frac{\exp(1.791-3.689\,\ell^-)}{1+\exp(1.791-3.689\,\ell^-)} \tag{3}$$

329

330 From this, we obtained the result that children experiencing negative learning had a 22

331 percent chance of choosing the risky option in the second trial, while those that did not

332 experience negative learning had a 95 percent chance (Figure 1).

333 To assess if any of the variables could explain the persistence of a choice made

334 in both trials, we defined $\pi_{i1,2} = P(\text{trial}_{i1,2}) = 1$ for the subjects that were risk-prone in

335 both trials, and $\pi_{i1,2} = P(\text{trial}_{i1,2}) = 0$ for those that were risk-averse in at least one trial.

336 Now only the variable quiet children, q, was selected, and the estimated model was

337

338 $$\text{logit}\,\pi_{i1,2} = 0.504 - 1.198\,q \tag{4}$$

339

340 or

341

342 $$\pi_{i1,2} = \frac{\exp(0.504-1.198\,q)}{1+\exp(0.504-1.198\,q)} \tag{5}$$

343

344 We found 58 children remaining risk-prone in both trials, but quiet children were found

345 to violate such a behavior. From the model, we obtained the result that quiet children

346 were only 33 percent as likely to repeat the choice of the risky option in the second trial

347 (Figure 2).

348 We also examined the explanatory variables that exclusively affected risky

349 choice in the first trial. Here digit ratio d was the only variable selected, and the

350 estimated model was

351

352 $$\text{logit}\,\pi_{i1} = 45.80656 - 45.12038\,d \tag{6}$$

353

354 or

355

356 $$\pi_{i1} = \frac{\exp(45.80656-45.12038\,d)}{1+\exp(45.80656-45.12038\,d)} \tag{7}$$

357

From this, we obtained the result that children with smaller 2D:4D ratios were 98.6 percent as likely to be risk-prone in the first trial, and that this did not occur in the second trial (Figure 3). However, gender and emotions were also important characteristics figuring in the choice of the risky option in the first trial because those variables were correlated with the digit ratio (Table 1). The fact that only the digit ratio was selected meant that the latter fully incorporated the effects arising from the other explanatory variables.

Table 1. Correlation between explanatory variables

	digit ratio	boys
Boys	−0.482338	
emotionally aroused children	−0.245289	0.263589

4. Discussion

Here we have extended the result of the risk-seeking behavior of monkeys in a visual gambling task (McCoy and Platt, 2005) to human children. In the study with monkeys surgical procedures were carried out on the heads of the animals to enable the use of microelectrode recording techniques to measure activity of individual neurons. Obviously, such a procedure is inconceivable in experiments on humans. However, we can still make well-informed deductions about the brain processes involved in our children's experiment. As in the monkey experiment, we hypothesized that children's posterior cingulate cortex is likely to have been activated in making the choice of the risky target in both the first- and second trials. The children's anterior cingulate cortex may also have been activated by the reinforcement learning occurring between the first trial and the second. These speculations are left for confirmation in future neuroscience research.

One implication of our study is that humans do not seem be born risk averse, but become risk averse. This is in line with previous work suggesting that people's risk attitudes may originate in accumulated learning rather than in human traits (March, 1996). Such a hypothesis could be evaluated in our experiment, because it incorporated a learning ingredient.

Whereas the monkey study relied on training procedures, we were saved that step in our own experiment because we could properly sample children in their preschool years. They could be expected to be able to make choices without having already made many of them in the past. This ensured that the choices they made were not bounded by too many negative experiences. By repeating the experiment after

392 school snack time, we allowed for reinforcement learning to take place at a learning rate
393 that is arguably large.

394 We also sought to assess whether an anthropometric feature such as digit ratio,
395 which proxies prenatal testosterone, predetermined children's choices. Digit ratio did
396 matter in the first trial of the experiment, thus suggesting that hormones may
397 predetermine a subject's choice. However, the fact that the digit ratio did not interfere
398 with the choices made in the second trial suggested, too, that hormones could not
399 always overcome learning. This deduction is in line with previous findings showing that
400 inherent traits influence choice but cannot outweigh learning (March, 1996).

401 Emotionally quiet children were found to be important in our experiment
402 because they were more susceptible to the reinforcement learning related to negative
403 experiences. Only 33 percent of the quiet children found to be risk prone in the first trial
404 continued to be risk prone in the second. We thus theorize that such an emotional state
405 is more likely to be overcome by rational brain processes, and favor the behavior where
406 rationality is more likely to ensue. This conjecture fits the finding that the prefrontal
407 cortex imposes self-control when spontaneous emotions otherwise would favor self-
408 destructive behavior by recruiting deliberative emotions through directed imagery and
409 thought (Giner-Sorolla, 2001).

410 Risk attitudes evolve (Robson, 1996) and risk preferences may change over the
411 life cycle. Like children, adolescents are risk prone, and this behavior may be
412 biologically driven (Steinberg, 2004). Adolescent risky behaviors can have adaptive
413 benefits in terms of development of independence and survival without parental
414 protection (Kelley et al., 2004). Adolescent neurodevelopment occurs in brain regions
415 associated with motivation, impulsivity, and addiction. Here risky behavior is a
416 transitional trait explained in part by maturational changes in the frontal cortical- and
417 sub-cortical monoaminergic systems (Chambers et al., 2003). Our children's experiment
418 complements these adolescent studies by suggesting that while hard-wired traits such as
419 hormones may also play a role, humans are not necessarily born risk averse.

420 Gender differences matter in risk taking (Byrnes et al., 1999). If anything, girls
421 are more risk averse. Our results suggested that this is valid for little girls, too. In the
422 first trial, 25 percent of girls were risk averse as against only 15 percent of boys. This
423 continued to hold true in the second trial, where 33 percent of girls were risk averse as
424 against only 29 percent of boys. Also, the seven boys that were described as aroused in
425 our experiment were risk seeking in both trials. However, we also found that the

426   proportion of quiet boys did not differ significantly from that of quiet girls (15.38 and

427   14.58 percent, respectively). Irrespective of gender, quiet children were less likely to be

428   risk-prone in the second trial of the experiment.

429   The results of the monkey- and children's experiments must be related to the

430   previous famous one where patients with prefrontal damage and health subjects

431   (Bechara et al., 1997) made choices of a sequence of cards from four decks. In that

432   experiment, both groups learned the payoffs from the previous play. Two decks had

433   more cards with extreme wins and losses, and thus negative expected value. The other

434   two decks had less extreme outcomes and positive expected value. After large-loss

435   cards were encountered, the patients rapidly returned to the high-paying risky decks; as

436   a result, they went bankrupt more often. But, the patients did not store the pain of

437   remembered losses as normal subjects did because prefrontal damage disconnects the

438   cognitive- and affective systems. We deduce that monkeys and children share the same

439   neural substrate with the patients of that experiment. Monkeys and children possibly

440   cannot store the pain of remembered losses as adult humans can. Fewer negative

441   experiences of losses in risky choices may explain this behavior in children. However,

442   as they accumulate losses, learning plays a role in their choices and thus they become

443   more risk averse.

444   We were cautious about the possible effects of satiety after snack time in the

445   choices made in the second trial. After all, a child that chose the risk option in the first

446   trial and was successful in getting a full glass, possibly would not try the risky option

447   again in the second trial if it were already satiated. The opposite holds true of the

448   children that got an empty glass after choosing the risky option in the first trial. Thus,

449   we also considered satiety as another explanatory variable (Section 3.3) only to find that

450   it had no influence in the choices made in the second trial.

451
452   **Acknowledgments**
453
456
457
458   **References**
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