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23 **Abstract**
24

25 A recent neurobiology study showed that monkeys systematically prefer risky targets in
26 a visual gambling task. We set a similar experiment with preschool children to assess
27 their attitudes toward risk and found the children, like the monkeys, to be risk seeking.
28 This suggests that adult humans are not born risk averse, but become risk averse. Our
29 experiment also suggests that this behavioral change may be due to learning from
30 negative experiences in their risky choices. We also showed that though emotional
31 states and predetermined prenatal testosterone can influence children's preferences
32 toward risk, these factors could not override learning experiences.
33

34 *JEL classification: C92, D81, D87*
35

36 *PsycINFO classification: 2300*
37

38 *Keywords: Risk; Children*
39

40 **1. Introduction**

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

55 Several anomalies of the expected utility theory have been well documented in
56 experimental economics, the most important being the Allais paradox (Allais, 1953). As
57 a result, a number of generalizations have been proposed (Tversky and Kahneman,
58 1992). The most prominent theoretical alternative is the prospect theory (Kahneman and
59 Tversky, 1979). This psychological approach posits that what influences risk attitudes is
60 not the expected outcome of a choice but the distinct reactions to gains and losses;
61 expected utility theory is right (and people are really risk averse) only for gains.
62 Cumulative prospect theory (Tversky and Kahneman, 1992) updates prospect theory to
63 consider high- and low probabilities. People are risk averse for gains of high probability
64 but also for losses of low probability, and are risk seeking for losses of high probability
65 but also for gains of low probability. Such developments justify why the same person
66 can show distinct attitudes toward risk, such as insuring a car used to drive to the
67 casino. The anomalies (Camerer et al., 2005) and prospect theory itself (Trepel et al.,
68 2005) seem to be tuned to the functioning of the brain.

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

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

97 The other limbic area of particular interest in our study is the posterior cingulate
98 cortex, which is also involved in risky decision-making (McCoy and Platt, 2005). The
99 posterior cingulate cortex translates subjective valuation signals into choice by making
100 connections with brain areas implicated in processing reward, attention, and action
101 (Vogt et al., 1992). This area is activated by the likelihood of rewards that are uncertain
102 in either amount (Smith et al., 2002) or time (Kable and Glimcher, 2007). Neurons in
103 the posterior cingulate cortex physiologically respond to visual stimuli (Dean et al.,
104 2004) after visual-orienting movements (Dean et al., 2004; Olson et al., 1996) and
105 rewards (McCoy et al., 2003). Thus, the posterior cingulate cortex contributes to
106 decision-making by evaluating external events and actions with respect to the subjective
107 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).

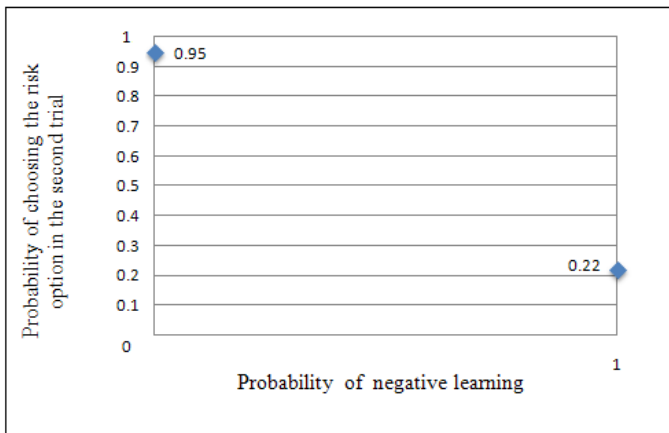
183 As expected (Manning, 2002), boys had an average 2D:4D ratio of 0.973
184 (standard deviation = 0.015), while girls had an average rate of 0.989 (standard
185 deviation = 0.015).

186

187 *2.2 Experiment*

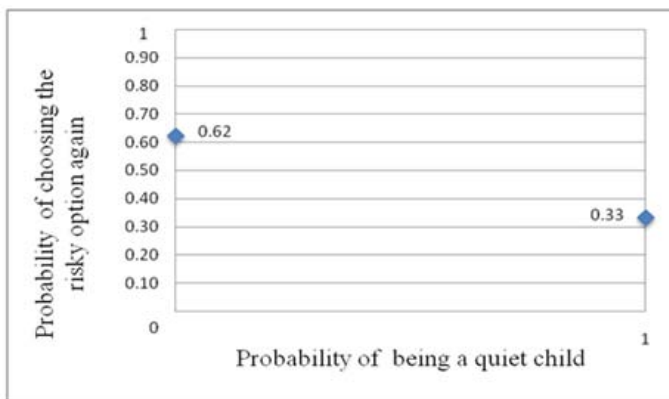
188 By setting the value 0 to the null hypothesis of risk aversion and the value 1 to
189 the alternative of risk seeking, we could not accept the null of risk aversion (mean = 0.8
190 prior to snack time, mean 0.69 after snack time, two-sided t -test < 0.0001 , $n = 100$).
191 Repetition of the trial 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).



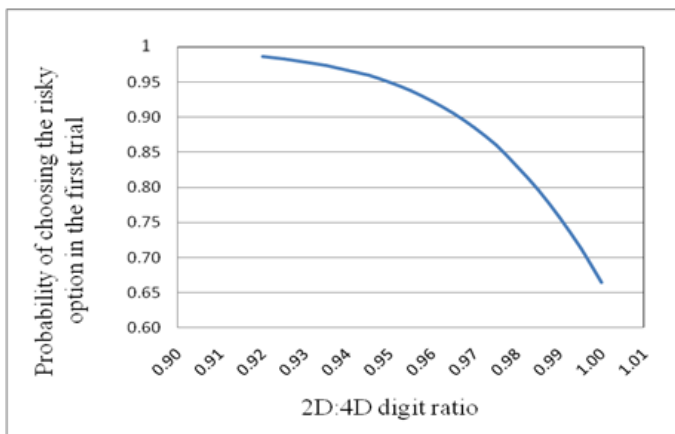
206
 207 Figure 1. Children that had their expectations frustrated in the first choice of a risky
 208 option were less likely to choose the risky option in the second choice. Those
 209 experiencing negative learning ($P(\ell^-) = 1$) had a 22 percent chance of choosing the
 210 risky option in the second trial, while those that did not experience negative learning
 211 ($P(\ell^-) = 0$) had a 95 percent chance of choosing the risky option in the second trial.
 212

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



221
 222 Figure 2. Quiet children ($P(q) = 1$) were only 33 percent as likely to repeat the choice of
 223 the risky option in the second trial. In contrast, the others (aroused-, happy-, calm-, and
 224 fearful children) ($P(q) = 0$) were 62 percent as likely to choose the risky option again in
 225 the second trial.
 226

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 Figure 3. Children with higher prenatal testosterone were more likely to seek risk in the
236 first trial. Subjects with smaller 2D:4D digit ratios were 98.65 percent as likely of being
237 risk prone, whereas subjects with a ratio approaching one were found to be only 66.5
238 percent as likely of being risk prone in the first trial. However, prenatal testosterone did
239 not matter in the second trial.
240

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-cm² 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

$$308 \quad \text{logit} \pi_{ij} = \log \frac{\pi_{ij}}{1-\pi_{ij}} = \beta \mathbf{x}_{ij} \quad (1)$$

309

310 where $\mathbf{x}_{ij} = (x_{1j}, \dots, x_{pj})$ 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

$$323 \quad \text{logit} \pi_{i,2} = 1.791 - 3.689 \ell^- \quad (2)$$

325 or
 326

$$327 \quad \pi_{i,2} = \frac{\exp(1.791 - 3.689 \ell^-)}{1 + \exp(1.791 - 3.689 \ell^-)} \quad (3)$$

329 From this, we obtained the result that children experiencing negative learning had a 22
 330 percent chance of choosing the risky option in the second trial, while those that did not
 331 experience negative learning had a 95 percent chance (Figure 1).
 332

333 To assess if any of the variables could explain the persistence of a choice made
 334 in both trials, we defined $\pi_{i,2} = P(\text{trial}_{i,2}) = 1$ for the subjects that were risk-prone in
 335 both trials, and $\pi_{i,2} = P(\text{trial}_{i,2}) = 0$ 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

$$337 \quad \text{logit} \pi_{i,2} = 0.504 - 1.198 q \quad (4)$$

339 or
 340

$$341 \quad \pi_{i,2} = \frac{\exp(0.504 - 1.198 q)}{1 + \exp(0.504 - 1.198 q)} \quad (5)$$

343 We found 58 children remaining risk-prone in both trials, but quiet children were found
 344 to violate such a behavior. From the model, we obtained the result that quiet children
 345 were only 33 percent as likely to repeat the choice of the risky option in the second trial
 346 (Figure 2).
 347

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

$$351 \quad \text{logit} \pi_{i,1} = 45.80656 - 45.12038 d \quad (6)$$

353 or
 354

$$355 \quad \pi_{i,1} = \frac{\exp(45.80656 - 45.12038 d)}{1 + \exp(45.80656 - 45.12038 d)} \quad (7)$$

357

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

365 Table 1. Correlation between explanatory variables

366

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

367

368

369 **4. Discussion**

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

382 One implication of our study is that humans do not seem be born risk averse, but
383 become risk averse. This is in line with previous work suggesting that people's risk
384 attitudes may originate in accumulated learning rather than in human traits (March,
385 1996). Such a hypothesis could be evaluated in our experiment, because it incorporated
386 a learning ingredient.

387 Whereas the monkey study relied on training procedures, we were saved that
388 step in our own experiment because we could properly sample children in their
389 preschool years. They could be expected to be able to make choices without having
390 already made many of them in the past. This ensured that the choices they made were
391 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 healthy 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

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453

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456

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458 **References**

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