Do adolescents take more risks? Not when facing a novel uncertain situation

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Abstract

In real-world decision-making, sub-optimal risk-taking is characteristic to adolescents, which increases the chance of serious negative outcomes (e.g., road traffic accidents) for them. Nevertheless, we are still lacking conclusive evidence for an inverted U-shaped developmental trajectory for risk-taking, since it is typically not observed in laboratory-based studies. This raises the question whether adolescents are really more risk-takers or when facing a novel risky situation they behave just as children and adults do. To answer that, we used the Balloon Analogue Risk Task (BART) to assess the risky decision making of 173 individuals ranging in age from 7 to 29. The BART provided useful data for characterizing multiple aspects of risk-taking. Surprisingly, we found that adolescents were not more inclined to take risks than children or young adults. Participants in all age groups were able to adapt their learning processes to the probabilistic environment and improve their performance during the sequential risky choice; however, there were no age-related differences in risk-taking at any stage of the task. Likewise, neither negative feedback reactivity nor overall task performance distinguished adolescents from the younger and older age groups. Our findings prompt 1) methodological considerations about the plausibility of the BART and 2) theoretical debate about whether the amount of prior experience on its own may account for age-related changes in real-life risk-taking, since risk-taking in a novel and uncertain situation was invariant across developmental stages.

Keywords: risky decision making, risk-taking, adolescence, development, cross-sectional, age differences

INTRODUCTION

Adolescence is marked by changes in decision-making processes and – more specifically – by the escalation of risk-taking behavior. Typically, the occurrence of risk-taking behaviors follows an inverted U-shape pattern across development, being relatively low in childhood, increasing and peaking in adolescence, and declining again thereafter (for overviews, see, e.g., Reyna and Farley, 2006; Steinberg, 2004). While reports about everyday behaviors (such as accident and crime statistics) continuously demonstrate and prove the adolescent peak in risk-taking, data from representative samples in controlled laboratory conditions have started to accumulate only recently. These empirical results are mixed (Gladwin et al., 2011; Defoe, Dubas, Figner, & Aken, 2015), as not all experiments succeed to confirm elevated risk-taking among adolescents (e.g., Crone et al., 2008; Weller et al., 2010; Paulsen et al, 2011), or showing lower risk-taking behavior in the adolescent groups even in 'hot' affect-charged tasks (Steinberg et al., 2008). Thus, adolescent risk-taking remains puzzling, and more data is needed in order to reveal those crucial aspects of risky situations that produce the "real world" developmental pattern. Here we aimed to map ontogenetic changes of risk-taking in a wide developmental window and used a unified, reliable paradigm to characterize different aspects of behavior in uncertain risky situations.

The Balloon Analogue Risk Task (BART) (Lejuez et al., 2002) has been used for the empirical assessment of the developmental changes in risk-taking. The BART is a 'hot' risk-taking task with immediate outcome feedback on rewards and losses. In the task, people are required to make repeated choices where risk levels may be escalated or eliminated as a result of one's previous decisions. Thus the BART provides a link to decision-making accounts of risky behaviors dealing with sequential outcomes (e.g., gradually increasing alcohol intake or driving speed). Among adolescents of 11 to 15 years of age, self-reported pubertal status predicted risk-taking on a modified version of the BART beyond relevant demographic characteristics (Collado-Rodriguez, MacPherson, Kurdziel, Rosenberg, & Lejuez, 2014). Also, risk-taking propensity increased across three annual assessment waves in a sample of early adolescents (MacPherson et al., 2010). However, using a cross-sectional design, Humphrey and Dumontheil (2016) were not able to show significant differences in risk-taking behavior on the BART among 12, 15, and 17-year-olds.

As follows, it remains unclear whether there is a behaviorally measurable developmental change in risk-taking. Here, we contribute to the clarification in this field with data from a sample that includes a continuous range of ages that spans preadolescence through young adulthood. Moreover, in this study, we characterize multiple aspects of risk-taking behavior. Aiming to exploit the rich information provided by BART data, we computed both conventional and more refined measures. The latter ones grasp the adaptivity of the participants, reflecting a change in behavior as a function of previous experience and collected information throughout the task. As such, the results of our study may provide a deeper understanding of the developmental course of risk-taking under uncertainty.

METHOD

Participants

One hundred ninety participants between the ages of 7 and 29 took part in the experiment. We excluded participants because of technical problems (three participants), lack of engagement (two participants), atypical amount or quality of sleep relative to their age group or medication use (six participants), and showing extremely atypical behavior according to Tukey's (1977) criterion (more than three times the interquartile range) relative to their age groups along any of the risk-taking measures (six participants). One hundred and seventy-three participants remained in the final sample. Participants were clustered into five age groups between 7-10, 10-13, 13-16, 16-18 and 18-28 years of age. Table 1 summarizes the descriptive characteristics of the sample. None of the participants suffered from any developmental, psychiatric, or neurological disorders (based on the parental reports for children and adolescents, and based on self-reports for young adults). All participants gave signed informed consent (parental consent was obtained for children), and they received no financial compensation for participation. All experimental procedures were approved by the Institutional Review Board of the Eötvös Loránd University.

Table 1. Descriptive data of demographic and cognitive measures in the whole sample and the five age groups separately.

	n	*gender male/female*	*age M (SD)*	*digit span M (SD)*	*counting span M (SD)*	*Corsi blocks span M (SD)*	*phonemic fluency* M (SD)*
whole sample	173	78/95	14.61 (4.40)	5.54 (1.14)	3.42 (.86)	5.10 (1.06)	12.76 (4.49)
age groups							
7-10	29	14/15	8.91 (0.72)	4.72 (0.52)	2.68 (0.50)	4.38 (1.04)	8.30 (2.77)
10-13	42	21/21	11.20 (0.87)	5.17 (0.86)	3.28 (0.93)	4.75 (0.70)	11.48 (3.33)
13-16	31	17/14	14.56 (0.83)	5.74 (1.12)	3.75 (0.86)	5.58 (1.05)	14.25 (4.07)
16-18	38	16/22	16.91 (0.54)	5.68 (1.16)	3.46 (0.65)	5.50 (1.13)	14.65 (3.21)
18-29	33	10/23	21.38 (1.93)	6.36 (1.24)	3.88 (0.77)	5.24 (0.90)	16.96 (4.18)

** number of correct words*

Stimuli, design, and procedure

We used the Balloon Analogue Risk Task (BART), a well-validated and widely-used behavioral measure of risk-taking, developed by Lejuez et al. (2002). The structure and appearance of the BART were the same as described in previous studies (Fein & Chang, 2008; Kardos et al., 2016; Kóbor et al., 2015; Takács et al., 2015). This version of the task was written in E-Prime 2.0 (Psychology Software Tools, Inc.).

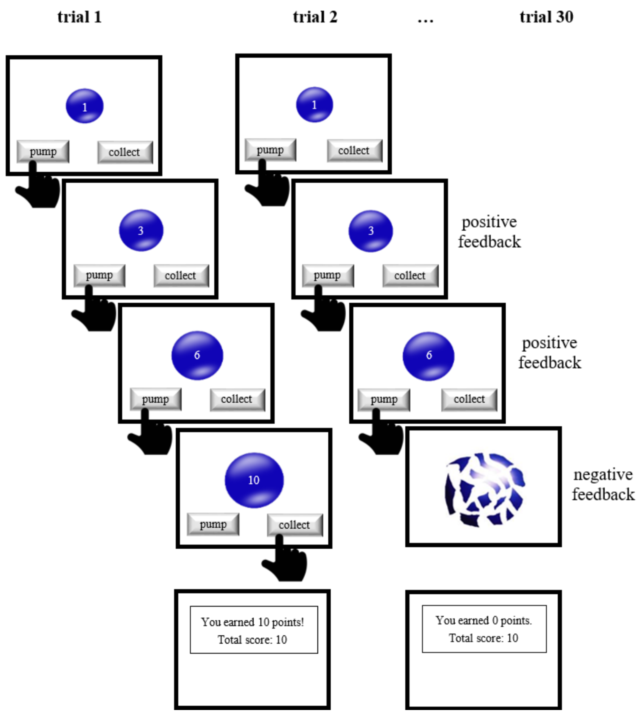

Figure 1**.** Schematic diagram for the BART. The BART is an ecologically valid model for the assessment of risk-taking behavior. During this task, participants repeatedly decide whether to continue or discontinue inflating a virtual balloon that can grow larger or explode. A larger balloon has both a higher probability of explosion but also a potential for greater reward.

During this task, participants repeatedly decided whether to continue or discontinue inflating a virtual balloon that could grow larger or explode. After each successful pump, the scores in a virtual temporary bank (the accumulated score on a given balloon) increased, as well as the size of the balloon. Instead of further pumping the balloon, participants could have finished the actual balloon trial and collected the accumulated score, which was transferred to the virtual permanent bank. Two response keys on a keyboard were selected either to pump the balloon or to finish the trial. There were two possible outcomes as results of a pump: The size of the balloon together with the score inside increased (positive feedback) or the balloon burst (negative feedback). The balloon burst ended the actual trial, and the accumulated score on that balloon was lost, but this negative event did not decrease the score in the permanent bank.

Five information chunks persistently appeared on the screen during the task: (1) the accumulated score for a given balloon in the middle of the balloon, (2) the score in the permanent bank, (3) the score collected from the previous balloon, (4) the response key option for pumping the balloon, and (5) the other response option for collecting the accumulated score. After collecting the accumulated score that ended the balloon trial, a separate screen indicated the gained score. This screen or the other one presenting balloon burst was followed by the presentation of a new empty (small-sized) balloon indicating the beginning of the next trial (Figure 1). Participants had to inflate 30 balloons in this version of the BART.

Concerning the structure of the task, each successful pump increased the potential reward but also the probability to lose the accumulated score because of balloon burst. Although the regularity determining balloon bursts was unknown to participants, it followed three principles: (1) balloon bursts for the first and second pumps were disabled; (2) the maximum number of successful pumps for each balloon was 19; (3) the probability of a balloon burst was 1/18 for the third pump, 1/17 for the fourth pump, and so on for each further pump until the 20th, where the probability of a balloon burst was 1/1. Thus, the probability of a balloon burst is given by the formula:

$$P(burst) = \begin{cases} 0, & if\ nr.of\ pumps < 3 \\ \dfrac{1}{21 - nr.of\ pumps}, & if\ nr.\ of\ pumps\ \geq 3 \end{cases}$$

One point was added to the temporary bank for the first successful pump, two for the second (i.e., the accumulated score for a given balloon was 3), three for the third (i.e., the accumulated score was 6); thus, the formula for the total accumulated score at the point of cashing out is:

$$\text{trial earning} = \sum_{i}^{nr.\ of\ pumps} \mathrm{i}$$

According to the instructions, participants were asked to achieve as high score as possible by inflating empty virtual balloons on the screen. They were informed that the participant with the most total earning in a subgroup of 10 was rewarded (the reward's identity was unknown to the participants during data acquisition and changed according to the age groups).

Risk-taking measures

The BART allowed us to quantify multiple aspects of risk-taking. We calculated four conventional BART measures: the mean number of pumps, the mean adjusted number of pumps (mean number of pumps on unexploded balloons; see Lejuez et al., 2002), the number of balloon bursts

(Schmitz et al., 2016) and the earnings (Koscielniak et al., 2016; Schmitz et al., 2016). In the analyses, we either used these measures averaged across all trials or in three bins (1-10 trials, 11-20 trials, and 21-30 trials), in order to be able to assess changes in risk-taking across the 30 trials.

One potential drawback of the conventional measures might be that they do not take into account the actual experience of the participant, which – due to the probabilistic structure of the task – is highly variable even for participants with identical behavior. BART data provides information above and beyond the conventional measures, allowing for the assessment of further important aspects of risk-taking (Schmitz et al., 2016). Therefore, we computed the *post-explosion reactivity* (which in Schmitz et al., 2016 is referred to as Δ post-loss pumps), that is the mean number of pumps relative to the pumps at the previous balloon explosion (or the mean number of pumps in the case of more subsequent bursts), averaged across all explosions in the task. In this measure, we include all trials from the first post-explosion trial to the last trial before the next explosion. We also computed *the immediate post-explosion reactivity* measure, which is also a relative measure, but here we only took into account the first post-explosion trial. Humphreys & Lee (2011) used an index corresponding to the immediate post-explosion reactivity as a measure of sensitivity to negative punishment. Accordingly, the two measures described above represent the extent to which participants adjust their responses to the negative feedbacks. If the post-explosion reactivity/immediate post-explosion reactivity score is 0, it shows that, on average, the participant inflated to the highest level where the balloon did not explode yet in the latest explosion trial. A negative value indicates less risk-taking, and a positive value indicates more risk-taking than it would be perfectly adapted according to the information from the negative feedback. Note that in the case of these two measures, the bin-wise analysis was not possible, only the conventional measures, since the number of data points taken into account was restricted by the number of balloon bursts.

RESULTS

We assessed whether a quadratic model accounted for the developmental change of BART measures. We found that none of the BART measures followed an inverted „U" shape across development (all *p*s > .286) (Figure 2). Furthermore, one-way ANOVAs with AGE GROUP (7-10, 10-13, 13-16, 16-18, 18-29) as a between-subjects factor on every BART measure were conducted. There were no significant differences in any of the BART measures among the age groups (all *p*s > .234 for the main effect of age). In order to be able to conclude whether our data supported the lack of developmental changes, we conducted Bayesian ANOVAs, as well. According to Lee and Wagenmakers (2013), values of the Bayes Factor (BF_{01}) larger than 1 indicate anecdotal evidence for the lack of group differences, while BF_{01} values larger than 3 indicate moderate evidence for the lack of group differences. We found moderate to strong evidence for the lack of age effects on all BART measures (all BF_{01}s > 6.959) (Supplementary Table S1).

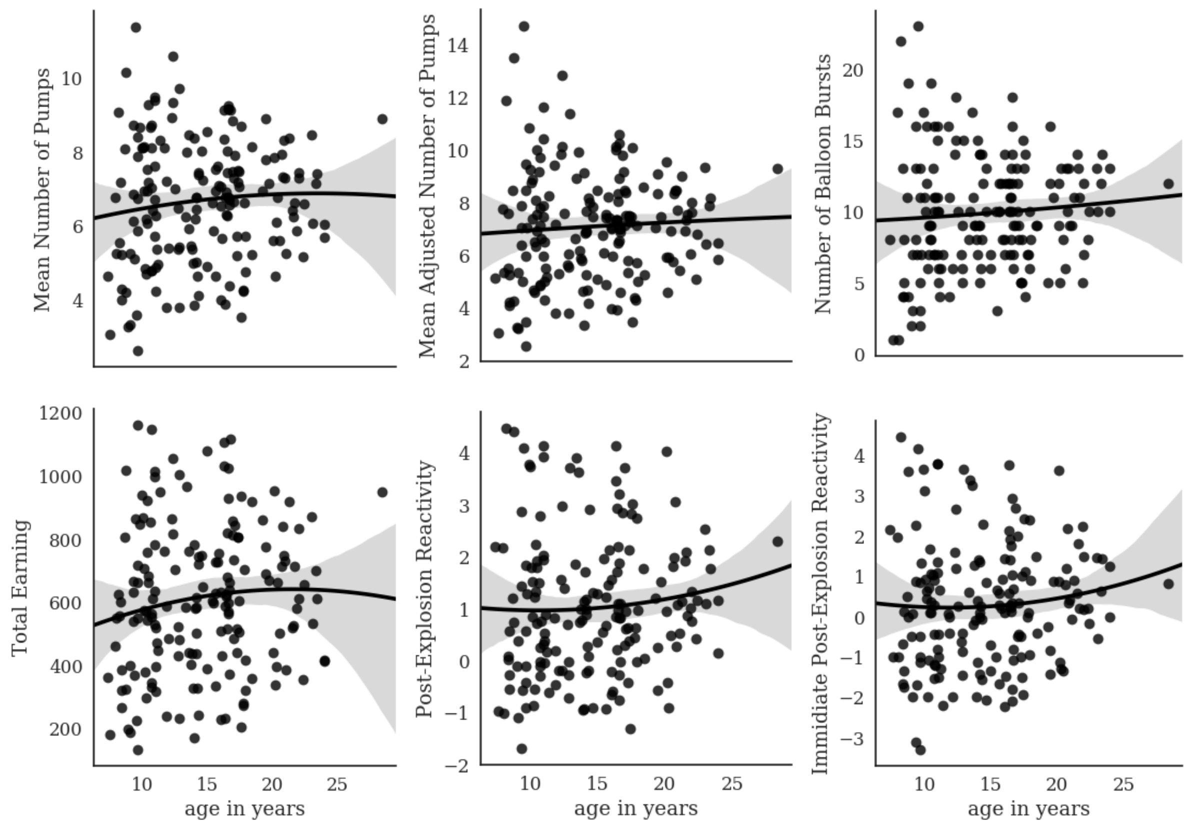

Figure 2. Quadratic regression models fitted to developmental data on six BART measures. None of the models were significant. *Note* Higher numbers indicate greater risk-taking. Grey bands represent the 95% confidence intervals.

Next, we assessed the developmental modulation of the *pattern* of risk-taking across the 30 trials. For this end, we conducted mixed design ANOVAs with BIN (1-10 trials, 11-20 trials, 21-30 trials) as the within-subjects factor and AGE GROUP (7-10, 10-13, 13-16, 16-18, 18-29) as the between-subjects factor. The dependent variables were the mean number of pumps, the mean adjusted number of pumps, the number of balloon bursts, and the earnings, respectively. Risk-taking was gradually heightened across the trials as shown by the main effect of BIN (all ps < .001) on the mean number of pumps, the mean adjusted a number of pumps, and the earning. The number of balloon bursts, however, did not change across trials (p = .348). Most importantly, we found no significant BIN*AGE GROUP interaction (all ps > .459) (Figure 3). The results of the Bayesian mixed design ANOVAs confirmed the absence of the BIN*AGE GROUP interaction, regarding all BART measures. The models without the interaction effects could account for the data better than the models with the interaction effects (all BF_{01}s for the models containing only the main effects are at least 39.960 times larger than the BF_{01}s for the models containing both the main effects and interaction effects, see Supplementary Table S2). Moreover, the simpler model containing only the main effect of BIN could account for the data better than the model containing the effects of both BIN and AGE, confirming the lack of age-related changes. Thus, the risk-taking uptrend across trials is characteristic to the sample, irrespectively of developmental phase.

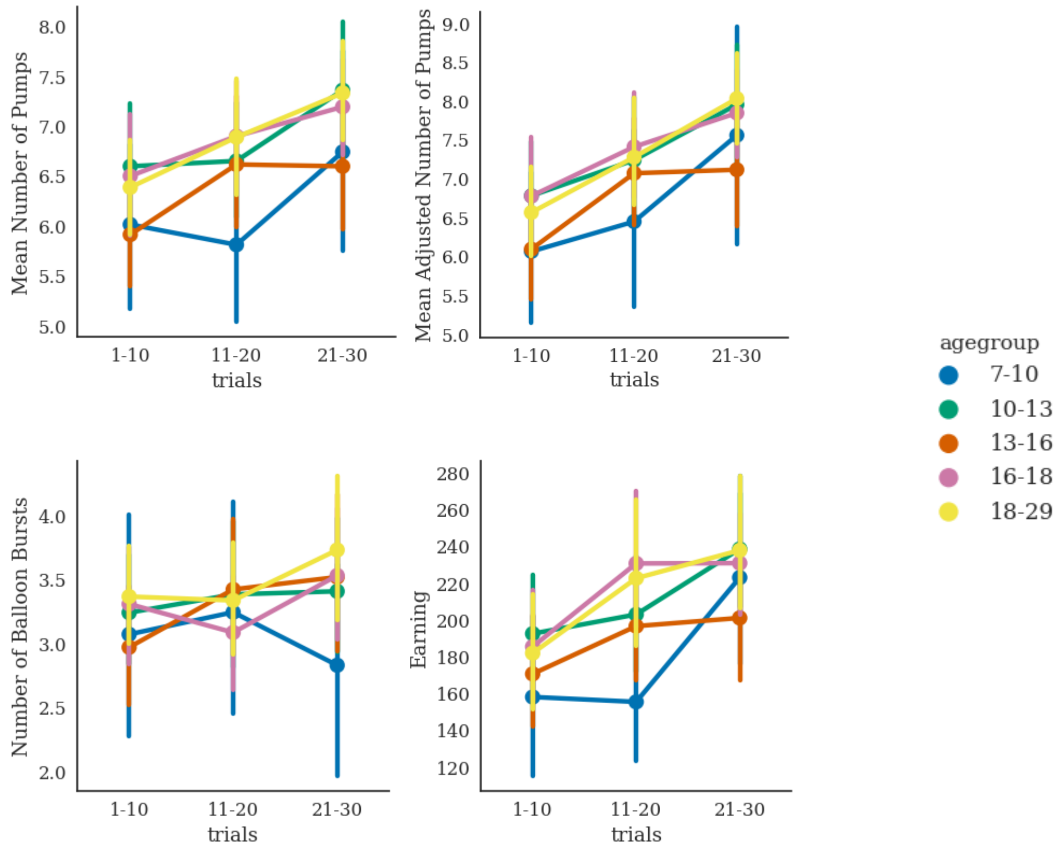

Figure 3. Change in risk-taking across three bins in the BART by age groups (indicated by different shades of blue), as reflected by four measures. The mean number of pumps, the mean adjusted number of pumps, and the earning are higher as the task proceeds, while the number of the balloon bursts remain unchanged. This behavioral pattern characterizes all five age groups, with no significant differences among them. *Note* Higher numbers indicate greater risk-taking. Error bars represent the 95% confidence intervals.

DISCUSSION

Despite the mounting real-life accounts for the striking changes in adolescent risk-taking, findings on age differences have remained conflicting. Also, many existing studies are limited in accounting for what we observe in real life either by the too narrow developmental sample or by the questionable reliability and ecological validity of the tools/methods. Here we aimed to assess risk-taking using the same experimental context that allows for measuring multiple aspects of sequential risk-taking in a relatively long period of ontogeny. To the best of our knowledge, the current study is the first to examine the developmental trajectory of risk-taking under uncertainty from childhood to young adulthood, cross-sectionally. We were not able to show age-related changes in risk-taking measures. Moreover, the results of Bayesian analyses proved that an *adevelopmental model* of sequential risk-taking data is the most plausible. Overall, the lack of age-related changes was consistently found for the overall risk-taking as well as for the course of risk-taking across multiple decision situations.

Our firmly negative results may be surprising, as they neither fit into the theories of adolescent risk-taking nor fall into the line of empirical results showing an inverted U-shaped developmental course of risk-taking. For example, neurodevelopmental imbalance models suggest that there is a potential for an imbalance between cognitive and affective processes in adolescence (Somerville & Casey, 2010; Steinberg, 2007), and these models postulate in particular that in emotionally charged ('hot') situations, adolescents' hypersensitive motivational-affective system often overrides cognitive control capacities that adolescents might have. Indeed, meta-regression analyses revealed that adolescents take more risks than adults on 'hot' tasks with immediate outcome feedback on rewards and losses (Defoe et al., 2015). Both MacPherson et al. (2010) and Lejuez et al. (2014) showed that risk-taking elevates across multiple waves of annual assessments in an adolescent sample. However, in this study, we showed that risk-taking levels rise across a single session of BART as well – which is possibly due to learning. Therefore, it becomes hard to interpret the results of the longitudinal studies mentioned above, since the differences among the annual assessments might reflect both developmental changes and trial-by-trial changes captured within sessions.

The flat developmental curve derived from our cross-sectional data prompts to consider the possibility that decision-making processes taking place in uncertain and affect-charged situations might not all be subject to ontogenetic changes. Thinking of human decision-making as Bayesian inference (e.g. Griffiths, Kemp & Tenenbaum, 2008), it depends on estimated probability distributions based on previous observations, with other words, on the *prior*. Adolescents, having had less experience, have less information available for representing the probabilistic structure of decision situations via *prior*s. Along these lines, we can speculate that differences not only in the decision-making processes per se, but also differences in the reliability of the priors that serve as input to those processes can account for the real-life observations about adolescent risk-taking. In this study, where priors were equalized between groups since none of the participants had previous experience with the task, age groups did not diverge in terms of risk-taking behavior.

Another possible explanation of our results is of a methodological nature; namely, the BART may be not entirely capable of modeling all crucial components of "real-life" risky situations, hence, may not be suitable for capturing age-related changes in risk-taking. Future research is needed to properly examine these suppositions outlined above. Here we confine ourselves to suggest further refinement of the theories of adolescent risk-taking in order to be able to pinpoint the crucial dispositional and situational factors that are developmentally determined.

Taken together, the current findings contribute to the vast literature of adolescent risk-taking by showing substantial evidence for no developmental changes from 7 to 29 years of age. While most studies in this field employ one or two measures, here we conducted a multivariate assessment of risk-taking by looking separately at the behavior 1) on trials with no negative feedback, 2) the change in behavior after a negative feedback, 3) and overall task performance, in the BART. Despite these and other methodological strengths, our study is not conclusive, it rather opens up both theoretical and methodological questions, thus warranting more extensive data analysis and refinement of theoretical frameworks in this field.

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Supplementary Tables

Table S1. Summary of the results from both frequentist and Bayesian Univariate ANOVAs performed on all BART measures in the five age groups.

	AGE GROUP		
Measure	*F*	*p*	BF_{01}
Mean Number of Pumps	1.119	.313	9.366
Mean Adjusted Number of Pumps	.681	.606	19.902
Number of Balloon Bursts	.406	.804	30.037
Total Earning	1.404	.235	6.959
Post-Explosion reactivity	.523	.719	24.464
Immediate Post-Explosion reactivity	.523	.719	24.533

Table S2. Summary of the results from both frequentist and Bayesian mixed design ANOVAs performed on all BART measures in three bins of the BART and five age groups.

	BIN			AGE GROUP			BIN*AGE GROUP		BIN+AGE GROUP + BIN*AGE GROUP	BIN+AGE GROUP + BIN*AGE GROUP / BIN+AGE GROUP
Measures	*F*	*p*	BF_{01}	*F*	*p*	BF_{01}	*F*	*p*	BF_{01}	BF_{01}
Mean Number of Pumps	16.484	< .001	1.006e-5	1.259	.288	5.259	.971	.459	0.002	39.960
Mean Adjusted Number of Pumps	27.778	< .001	6.342e-10	.974	.424	7.435	.669	.719	4.074e-7	99.365
Number of Balloon Bursts	1.060	.348	15.963	.406	.804	29.188	.786	.615	33992.075	74.640
Earning	12.559	< .001	4.042e-4	1.497	.205	8.803	.897	.519	0.177	59.000

Note. The BF_{01} is not computed for the BIN*AGE GROUP interaction on its own but for the model containing the main effects and the interaction, as well. The BF_{01}s in the last column indicate how much more probable is that the model without the interaction accounts for the data than the model with the interaction included.

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