Patterns of responding on a balloon analogue task reveal individual differences in overall risk-taking: Choice between guaranteed and uncertain cash.

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ABSTRACT

We explored the utility of analyzing within- and between-balloon response patterns on a balloon analogue task (BAT) in relation to overall risk scores, and to a choice between a small guaranteed cash reward and an uncertain reward of the same expected value. Young adults (n=61) played a BAT, and then were offered a choice between $5 in cash and betting to win $0 to $15. Between groups, pumping was differentially influenced by explosions, and by the number of successive unexploded balloons, with risk takers responding increasingly on successive balloons after an explosion. Within-balloons, risk takers showed a characteristic pattern of constant high rate, while non-risk takers showed a characteristic variable lower rate. Overall, results show that the higher number of pumps and explosions that characterize risk takers at a molar level, result from particular forms of adaptation to the positive and negative outcomes of choices seen at a molecular level.

Keywords: risk taking, impulsivity, choice, balloon analog task, BART, probabilistic rewards, molar-molecular analyses

Individuals differ widely on the amount of risk they take under similar circumstances (Byrnes, Miller, & Schafer, 1999; Mishra & Lalumière, 2010; Pietras, & Hackenberg, 2001; Rode et al., 1999; Wang & Dvorak, 2010). Those with a higher propensity to take risks are more likely to experience injuries (Cherpitel, 1999; Ryb et al., 2006), drug dependence (Bickel, Odum & Madden,1999; Bickel, Kowal & Gatchalian, 2006; Lejuez et al., 2002; Hopko et al., 2006; Robles et al., 2011; Reynolds et al., 2006;), alcohol abuse (Lejuez et al., 2002; Fernie et al., 2010; Richards et al., 1999), and pathological gambling (Petry & Cassarella, 1999; Reynolds et al., 2006).

Some situations involving risky choice are unique or infrequent like getting married or flying to outer space. But many opportunities for risky choice present themselves repeatedly over time; deciding to use or not to use drugs, choosing to drive after drinking, and buying a lottery ticket, are but a few examples. In the laboratory, risk taking is often studied as choice over multiple trials (Bechara et al., 1994; Lejuez et al., 2002; Mishra & Lalumière, 2010; Schreiber & Dixon, 2001; Reilly et al., 2006; Thaler & Johnson, 1990). One example of a multiple-trial laboratory model to study risk taking is the Balloon Analogue Risk Task (BART) developed by Lejuez and collaborators (2002). The BART is a computerized simulation that presents subjects with repeated opportunities to earn cash by pressing a button to simulate pumping air into a virtual balloon. Each pump deposits earnings into a temporary bank. With every choice to pump there is also an increasing chance for loss, as each pump brings another chance for the balloon to explode. To prevent losses, the player can save the earnings in a permanent bank at any point before the balloon bursts. Such action, however, also deactivates the current balloon, and starts a new trial. If the balloon bursts before the player saves these earnings, they are lost and a new trial begins. Thus, the total number of points earned in a session and the proportion of balloon explosions can serve as indicators of propensity to take risks. In fact, BART responding has been shown to positively correlate with self-report measures of impulsivity (Bornovalova et al., 2009; Holmes et al., 2009; Lejuez et al., 2002; Mishra & Lalumière, 2010; Mishra, Lalumière, & Williams, 2010; Vigil-Colet, 2007), risky sexual behaviors (Lejuez et al., 2004), drug abuse (Aklin et al., 2005; Crowley et al., 2006; Lejuez et al., 2002; Hopko et al., 2006), alcohol abuse (Lejuez et al., 2002; Fernie et al 2010), smoking (Lejuez et al., 2003), and general delinquency and gambling (Lejuez et al., 2003b). In addition, BART responding is associated with a higher proportion of risky decisions in other laboratory choice tasks (Mishra & Lalumière, 2010; Reynolds et al., 2006).

In balloon analogue tasks (BAT) such as the BART, responding is probabilistically followed by wins (added points) and losses (balloon explosions) over a fixed number of opportunities to choose; this is true for all players. Therefore, it is the particular ways in which individuals respond to these events that lead risk takers to accumulate a significantly higher number of points than non-risk takers over the entire

assessment. It is possible that analyzing the sequential effects that positive and negative outcomes have on subsequent responding at the individual level may shed light on how risk takers and non-risk takers differentially adapt to the common environment. Such an approach has proven successful in the past. The temporal relations between trial outcomes and subsequent responding were earlier investigated by Dickerson et al. (1992) and Delfabbro et al. (1999) in subjects playing poker machines. They found that betting rate increases after small wins and decreases after big wins, particularly in regular poker players. Similar results were observed by Schreiber & Dixon (2001) and Dillen & Dixon (2008) in subjects placing bets on a recreational slot machine. The authors found that response time on placing a bet varied within subjects as a function of the outcome on the immediately preceding trial. Specifically, trials following a loss had significantly shorter intertrial interval than trials following a win. Dillen & Dixon (2008), however, found that this pattern was not affected by the size of the payoff. Then, Pleskac & Wershbale (2012) found that subjects playing the BART show two different patterns of inter-response times (IRT) within balloons, and suggested that the way these patterns evolve may differentiate individuals with conduct disorder and substance abuse. And more recently, Jackson et al. (2013) found a characteristic negatively accelerated function of IRT durations across trials in the BART for all subjects; in addition, they found that subjects scoring higher on a psychopathy scale consistently exhibited higher response rates.

It is possible, therefore, that the overall level of risk-taking estimated by a multiple-trial risk task such as the BART might reflect the local distribution of responses relative to the distribution of wins and losses within a game, and that risk takers might react differently than non-risk takers to wins and losses. The purpose of this study was to analyze local patterns of responding on a multiple-trial risk task in relation to overall risk scores and to an actual choice between a small guaranteed cash reward and an uncertain reward of the same expected value.

METHOD

Subjects. Sixty-one college students volunteered to participate. Students were recruited from the departmental subject pool and received course credit for attending and completing the experimental session. The sample was composed of 57.4% female students (n = 35), and had median age of 22 years (range 18-38).

Procedure. All study procedures were approved in advance by the local institutional review board. The experimental tasks were completed individually in a single 30-minute laboratory session. Participants were instructed not to eat, drink or use cellphones during the task, and to use the computer mouse when making selections in the game. Participants were told that the choices they make, might impact the amount of money they receive at the end of the session.

Upon arrival, individuals were randomly assigned to 1 of 3 uncertain reward tasks: *Double or Nothing* (n=21), *More or Less* (n=20), and *Lottery* (n=20); then all participants played the balloon analogue task (BAT). Once the balloon task was completed, participants were individually taken to an adjacent room where the assigned uncertain reward task was administered. In every case, participants were given a detailed explanation of the task (see below) and asked to choose between $5 in cash and an uncertain amount of cash ($0, $5, $10, $15) that averaged $5 across participants. Participants then received the amount of cash resulting from their choice ($0 - $15). Data collection was done with a program written in Microsoft Visual Basic 6.0 running on dedicated computers. IBM SPSS 20.0 was used for data analysis.

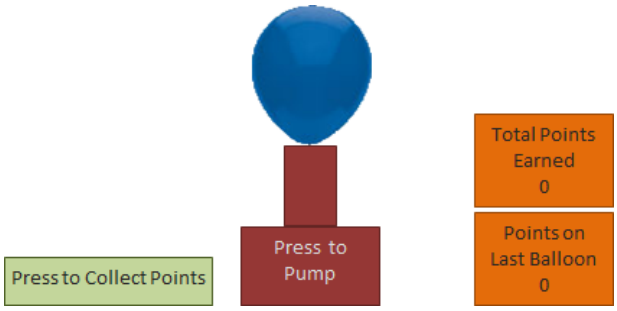

Figure 1. Main screen of the balloon analog task (BAT).

Balloon Analogue Task (BAT). The task used in this study was modeled after Lejuez et al. (2002) Balloon Analogue Risk Task (BART) and modified as described below. Although many features of the BART are present in the procedure used in this study, it is not known if the variants introduced to the current task might lead to different results. Therefore, to differentiate this experimental procedure from Lejuez et al. (2002) validated assessment task, we refer to it generally as a Balloon Analogue Task (BAT).

On the computer screen (see Figure 1) a balloon image appeared next to a button labeled "Press to Pump"; the participants were to click on this button to inflate the balloon. Each pump increased the balloon size by a constant amount and deposited 1 point into a temporary bank, which was not displayed on the screen. On average, balloons exploded after 64 pumps; for each subject, the 30 specific values assigned to subsequent balloons were randomly selected without substitution from the following list: 1, 1, 5, 6, 7, 7, 36, 37, 38, 46, 48, 55, 58, 59, 63, 64, 70, 73, 80, 82, 90, 91, 92, 95, 109, 119, 120, 121, 122, and 125. Thus, the probability of a balloon exploding on the first pump was 1/125; on the second pump if it did not explode on the first, 1/(125 - 1); on the third pump given that it did not explode on the first two, 1/(125 - 2); and so forth. At any time before a balloon explosion the participant could click on the button labeled "Press to

Collect Points." This action transferred the points accumulated in the temporary bank during the current balloon to a permanent bank where the points were safe for the remainder of the game. Transferring the points to the permanent bank also disabled the current balloon and started a new deflated one. On the other hand, if a balloon exploded, any points in the temporary bank were lost and a new balloon trial ensued. When a balloon exploded, a large "POP!" sign appeared across the screen clearly marking the end of the trial. The entire game consisted of 32 balloons, the first 2 being practice balloons programmed to explode at 32 and 10 responses, respectively. Data from the practice balloons were not included in the analyses. In addition to the number of pumps for each balloon and the number of unexploded balloons, response time on each balloon trial, and the time between mouse clicks within individual balloons were recorded. Shown on the screen adjacent to the balloon were 2 counters; one labeled "Total Points Earned," showing points earned during the entire game, and a second counter showing points earned on the preceding balloon only. The goal during the BAT was to get the largest number of points; the points did not have monetary value. The following directions were presented on the computer screen.

HOW TO PLAY THE BAT

- In this game you will get 32 balloons, one at a time.
- Click the button labeled **Press to Pump** to inflate the balloon.
- You will get 1 point in your temporary bank each time you press the pump.
- The goal is to get the largest amount of points.
- At any time you can save the points you have earned by clicking on the button labeled **Press to Collect Points**. Clicking this button will also start you on the next balloon.
- The amount you earned on the previous balloon is shown in the box labeled **Points on Last Balloon**.
- The amount you have earned during the game is shown in the box labeled **Total Points Earned**.
- **Be aware that at some point the balloon will blow up**.
- If the balloon blows up before you click the **Collect Points** button, the points earned with that balloon are lost.
- Exploded balloons do not affect your **Total Points Earned.**
- The number of pumps needed to explode varies for each balloon from one pump press to enough pump presses to make the balloon fill the entire screen.
- You decide how much to pump up each balloon before you collect the points.
- Ready?

Uncertain Rewards Tasks. After completing the BAT, participants were offered the monetary choice they had been randomly assigned. In every case participants were

asked to choose between the guaranteed and uncertain reward options by filling out a *choice selection form*. The forms clearly described the betting procedures and the possible outcomes in each game, and highlighted that the average prize was still $5 overall.

Double or Nothing. Subjects in this group were presented with the choice to take $5 in cash or bet it double ($10) or nothing ($0) on a coin flip. Participants who chose the $5 received the cash immediately; otherwise, the researcher flipped a coin and awarded $0 or $10 depending on the outcome.

More or Less. Participants were given a choice between a sealed envelope marked "$5" and a sealed envelope marked "$0 to $10." If the first option was selected, the envelope containing $5 was conferred. If the alternative option was selected, the participant received the envelope containing $0, $5, or $10. The amount of cash in specific envelopes was determined in advance, with the order of prizes randomized; both participants and researchers were blind to the envelopes content. The average prize was $5.

Lottery. Participants assigned to this task were presented with a choice between $5 and a chance to win $0, $5, $10, or $15 in cash on a lottery draw. If the lottery option was selected, one of 20 balls in a bingo cage was randomly drawn and the participant received the amount of cash printed on the ball. The prizes printed on the lottery balls averaged $5.

RESULTS

BAT Scores and Gambling Choice. Based on the extant literature on the BART we hypothesized that BAT scores would predict monetary choice, with those receiving higher risk scores being more likely to choose the uncertain monetary option. As proposed by Lejuez et al. (2002), we used the adjusted mean number of pumps per balloon (those that occur in unexploded balloons) as a measure of risk taking. Overall, 60% of all participants chose to risk their earnings; of those, 40% chose to gamble in the *More or Less* group, 57% in the *Double or Nothing* group, and 85% in the *Lottery* group. Figure 2 shows the distribution of adjusted mean number of responses by monetary choice; symbols represent individual means by task, and lines indicate group means. The distribution of scores for subjects taking the certain cash is relatively flat, while subjects choosing to bet are more heavily concentrated at the top. To assess the independent contribution of the number of adjusted pumps as predictor of risky choice (yes/no), a multiple logistic regression model was tested that also included group assignment (Double or Nothing, More or Less, and Lottery), sex, and age, as potential predictors. After accounting for age, sex, and group the model identified mean adjusted pumps (p = .016, Wald = 5.76) as a significant independent predictor of choosing to gamble (see Table 1). Although group assignment was not a significant predictor (p = .082, Wald = 5.00), the opportunity to play the Lottery was identified as a predictor of choosing to bet (p = .026, Wald = 4.98) when compared to the other two choice tasks.

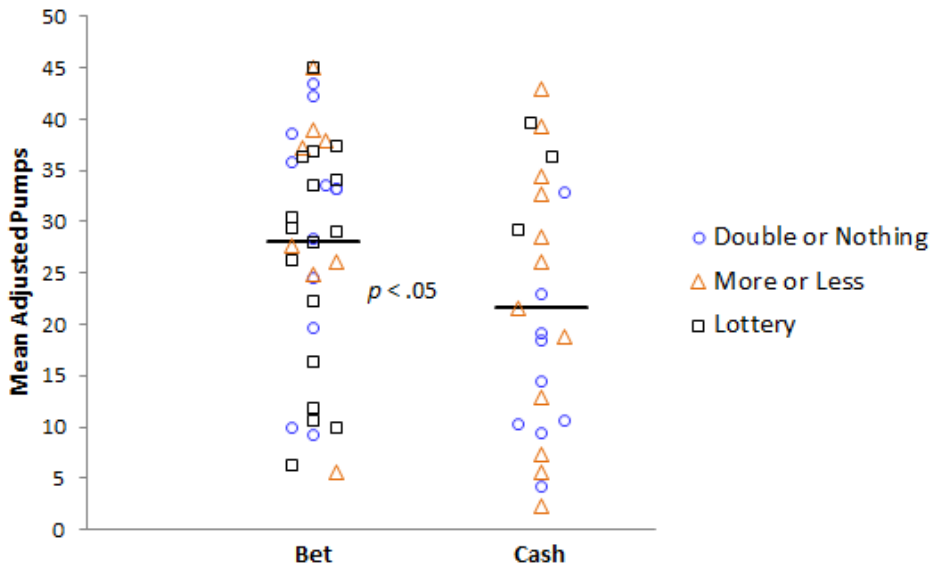

Figure 2. Mean adjusted number of pumps per balloon by group assignment for risk takers and non-risk takers. Symbols represent individual means by assigned choice task, and lines depict group means.

Local Response Patterns. We sought to determine if overall BAT scores were associated with particular patterns of responding within and between balloon trials. We speculated that balloon explosions might have a direct effect on subsequent responding, and that such effect might be critical to the differentiation between risk takers and non-risk takers. Because both the adjusted number of responses and the number of unexploded balloons are continuous (i.e., not dichotomous) variables measuring propensity to take risks as a single scale-free score, unless otherwise noted,

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
							Lower	Upper
Pumps per Balloon	0.135	0.056	5.764	1	**0.016**	1.145	1.025	1.278
Age	0.048	0.071	0.461	1	0.497	1.049	0.913	1.206
Sex (Male)	0.583	0.73	0.637	1	0.425	1.791	0.428	7.488
Group Assignment			5.01	2	0.082			
Lottery vs. DorN, MorL	8.054	3.61	4.978	1	**0.026**	3147.806	2.662	3722151
DorN vs. Lottery, MorL	0.86	1.792	0.23	1	0.631	2.363	0.07	79.277
Constant	-4.155	2.458	2.857	1	0.091	0.016		

C.I. = Confidence Interval; DorN= Double or Noting; MorL= More or Less

Table 1. Multiple logistic regression model for risky choice (Yes/No) as a function of the mean number of pumps per balloon, group assignment (Lottery, Double or Nothing, More or Less), and participant sex and age.

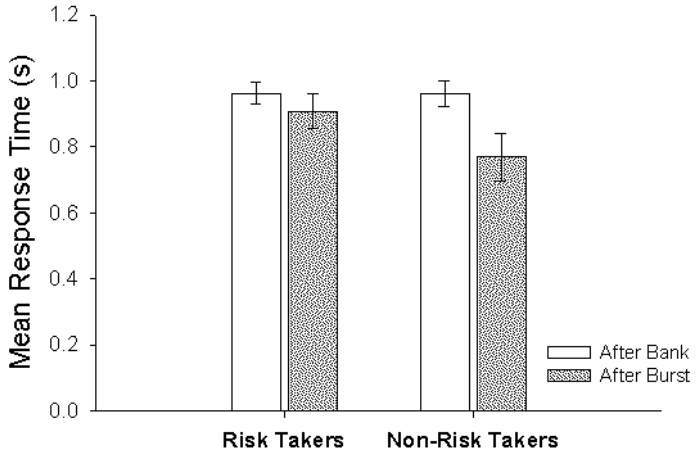

Figure 3. Mean response time (RT) and SEM after explosions (gray) and points transferred to permanent bank (black) for risk takers and non-risk takers. Mean RT was shorter after an explosion, independently of risk group.

we use each subject's actual monetary choice to classify them as risk takers (those who chose to bet) and non-risk takers (those who chose the guaranteed cash).

Response Time. The mean time to the first response on a balloon trial was calculated for risk takers and non-risk takers when the preceding balloon had ended in an explosion and when it had ended in the subject saving points to the permanent bank; results are shown on Figure 3. A two-way ANOVA with Choice (Bet vs. Cash) and Prior Outcome (Bank vs. Burst) as factors revealed longer RTs after having saved points to the permanent bank in the preceding trial (mean=.96, SEM = .024) than after having experienced an explosion (mean= .86, SEM = .049) $F(1, 1796) = 5.66$, $p = .018$, power = .57). The test revealed no differences in RT based on Choice or the interaction between the factors (both $p > .05$).

Effects of Balloon Explosions on Subsequent Responding. To assess the impact that individual balloon explosions and successfully cashed points had on subsequent responding, we calculated the mean number of pumps during unexploded balloons that occurred between each two explosions for risk takers and non-risk takers. Overall, 540 unexploded balloons were observed for risk takers, and 825 for non-risk takers. Because the number of unexploded balloons between two explosions depended concurrently on randomly selected burst values in conjunction with the subject's responses, we first looked at the length of the series of consecutive unexploded balloons for risk takers and non-risk takers to determine if the two obtained distributions were

numerically comparable. If two consecutive balloons exploded, then the series length was zero; otherwise, the mean number of pump responses on each consecutive

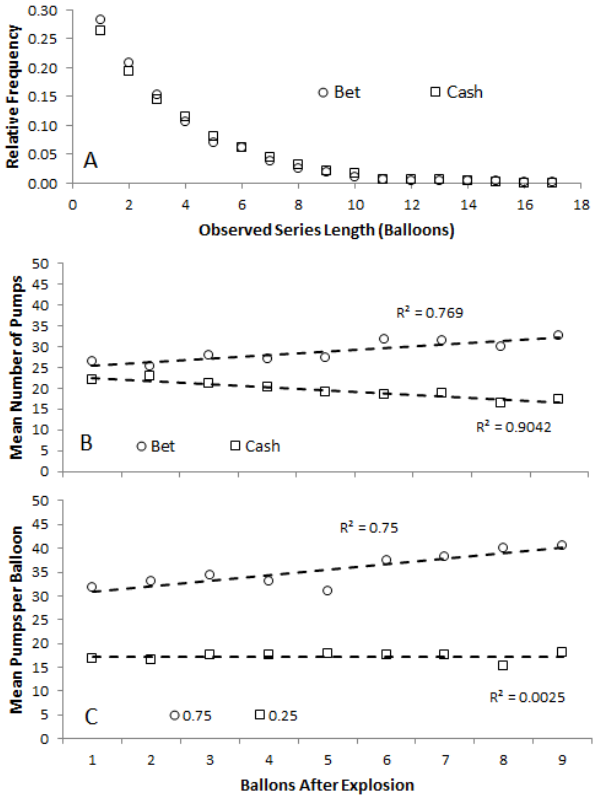

Figure 4. A. Obtained relative frequency distributions by length of the series of unexploded balloons that occurred between two consecutive explosions, for risk takers and non-risk takers. B. Mean number of pumps occurring in consecutive balloons after an explosion for risk takers and non-risk takers. C. Mean number of pumps occurring in consecutive balloons after an explosion for subjects in the top and bottom 25% of all BAT scores. Symbols represent observed means and lines depict model predictions. Balloon positions 1 through 9 in the series are shown in panels B and C; see Table 1 for the complete dataset.

unexploded balloon between two explosions was calculated. Figure 4-A shows the resulting relative frequency distributions of unexploded balloons by series length, for both groups. The observed series ranged in length between 1 and 17 balloons. The obtained group distributions were very similar, and well described by an exponential model ($R^2 > .99$; $p < .0001$). Accordingly, we proceeded to analyze responding in relation to distance from the preceding explosion. Figure 4-B shows the mean number of pumps for each balloon position in the series. Data points corresponding to balloons positions 10 to 17 were omitted from the analysis because the observed number of cases in each length category was less than 2% of the cases (see panel 4-A and the complete dataset

presented in Table 2). For series with length 1 to 9 the resulting response distributions show a clearly different pattern of responding for risk takers and non-risk takers, with risk takers pumping consistently more than non-risk takers across balloons. In addition, although similar in magnitude, immediately following an explosion the mean number of pumps was the lowest in the series for risk takers (26.5), and highest in the series for non-risk takers (22); then, the mean number of pumps in subsequent balloons monotonically increased for risk takers, and decreased for non-risk takers. Linear regression models of the mean number of responses per balloon in the series (length 1 to 9) account for 77% and 90% of the variance for risk takers and non-risk takers, respectively.

For comparison, we ran a similar analysis using the top 25% and bottom 25% of all BAT scores to classify subjects as risk takers or non-risk takers, regardless of their choice to bet or take the cash. Figure 4-C shows the mean number of pumps for each balloon position (1 through 9) in the series. As above, data points corresponding to balloons positions 10 to 17 were omitted from the analysis due to the small number of cases in each category. Consistent with the results described above (panel B), there is a clear separation of the distributions and a monotonically increasing mean number of adjusted pumps across balloons in the series for subjects in the top quartile (the risk takers) while the distribution for subjects in the bottom 25% of all BAT scores is essentially flat.

Responding Throughout the Session. To assess possible practice/ learning effects throughout the session we calculated the mean number of pumps on successive unexploded balloons for risk takers and non-risk takers (see Fig. 5). A negatively accelerated pattern of responding was observed for both groups, with risk takers showing a consistently higher mean number of responses per balloon throughout the session. We fitted the group data assuming an exponential raise to maximum model,

$$r = a(1 - e^{-bi}) \qquad \text{Eq. 1}$$

where r is the mean number of pumps per balloon and i is the balloon number in the session. Data for both groups were well described by the simple exponential function, accounting for 75% ($p < .0001$, power = 1.0) of the variance for risk takers, and 65% ($p < .0001$, power = 1.0) non-risk takers. It is worth considering that even at its max value the total number of responses per balloon was well below the expected optimal 64 responses. This difference in responding between the groups can be readily appreciated on Figure 6, which shows the probability of occurrence of response runs of length $\leq n$ in the session, $p(n)$. The shape of these distributions is similar, with risk takers consistently having longer response runs (median= 27) than non-risk takers (median = 19), and with less than 2% of all runs ≥ 64 pumps.

	Risk Takers		Non-risk Takers	
Balloon Position in the Series	Number of Cases	Mean Number of Responses	Number of Cases	Mean Number of Responses
1	234	26.50	145	22.00
2	171	25.43	106	22.95
3	126	27.87	77	21.02
4	88	27.07	63	20.38
5	57	27.23	42	19.04
6	51	31.75	34	18.37
7	32	31.59	23	18.72
8	21	30.10	16	16.56
9	15	32.73	11	17.25
10	8	28.50	10	13.40
11	5	26.40	4	9.25
12	4	36.75	3	10.00
13	3	28.00	3	12.67
14	3	15.67	2	15.00
15	3	15.33	1	1.00
16	2	10.50	0	0.00
17	2	12.00	0	0.00
Total	825		540	

Table 2. Number of consecutive unexploded balloons observed between two explosions for risk takers and non-risk takers; for each balloon position in the series (1-17) the average number of responses and the corresponding number of observations are presented. Series with length ≥10 balloons represent 5% of the cases (n= 30) for risk takers and 4% of the cases (n = 23) for non-risk takers.

Within-Balloon Response Patterns. The average response rate during unexploded balloons was 2.9 pumps per second for risk takers (SEM = .04), and 2.52 pumps per second for non-risk takers (SEM = .05; $t = 5.738$, $df = 1363$, $p < .0001$, power = 1.0). On average, risk takers worked for 10.1 s (SEM = .24) on each non-exploded balloon, while non-risk takers completed a non-exploded balloon in 8.72 s on average (SEM = .26; $t = 3.682$, $df = 1363$, $p = < 0.001$, power = .96). In other words, risk takers pumped each balloon faster and for a longer time than non-risk takers. Figure 7 shows the 30 cumulative response runs for 4 selected subjects; each line corresponds to a single balloon. For risk takers (Left Panels), responding during unexploded balloons was often characterized by a high steady rate followed by a decrease in response rate right before cashing points to the permanent bank; conversely, for non-risk takers (Right Panels), responding within balloons was often characterized by a wavy pattern resulting

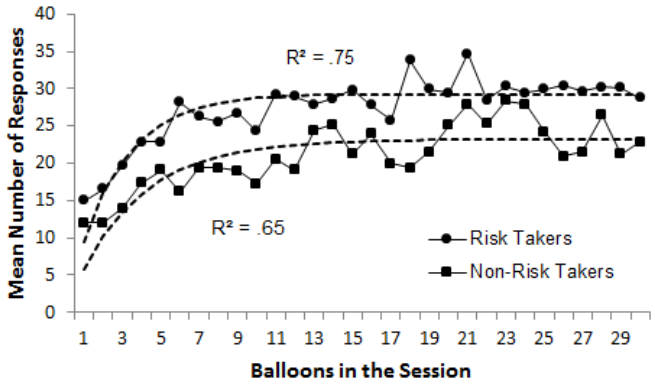

Figure 5. Mean number of adjusted responses throughout the session for risk takers and non-risk takers. Symbols and continuous lines depict obtained data and broken lines show model predictions.

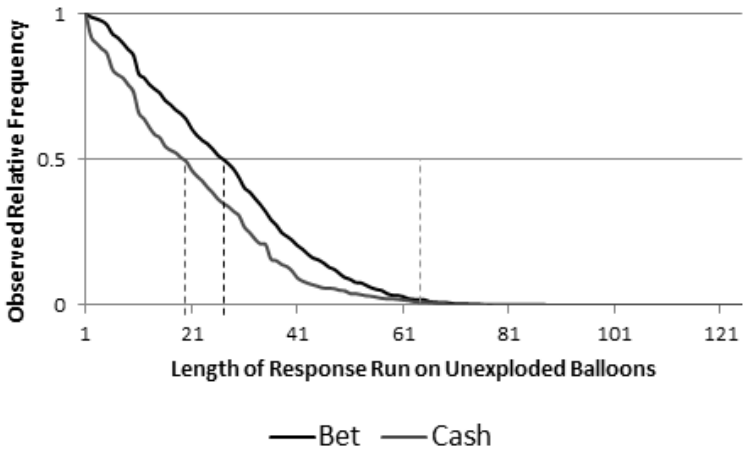

Figure 6. Probability of response runs with length ≤ *n* for risk takers and non-risk takers during the entire session. Median response runs for both groups (27 vs. 19) and expected median response run (64) are marked by broken lines.

from alternating periods of higher and lower rates, and a lower average number of responses per unexploded balloon. The observed patterns were not exclusive to one group or the other; most subjects showed a combination of both. However, 5 blind raters of charts depicting all 30 cumulative curves for all 61 subjects correctly classified the charts as belonging to risk takers or non-risk takers in 60% to 75% of the cases.

DISCUSSION

We found that participants who made the most pumps per unexploded balloon in the BAT were more likely to choose the riskier option on a one-time monetary choice. This is congruent with the extant literature on the BART as predictor of propensity for risk taking. In addition, consistent with previous results (Bornovalova et al., 2009;

Lejuez et al., 2002, 2007; Weatherly et al., 2008), we found that participant sex and age were not predictors of risky choice in the laboratory.

In this study, the assigned risk tasks contributed to the participants' choice between guaranteed and uncertain cash: subjects that were given the opportunity to play the Lottery were more likely to gamble compared to the other two groups. We

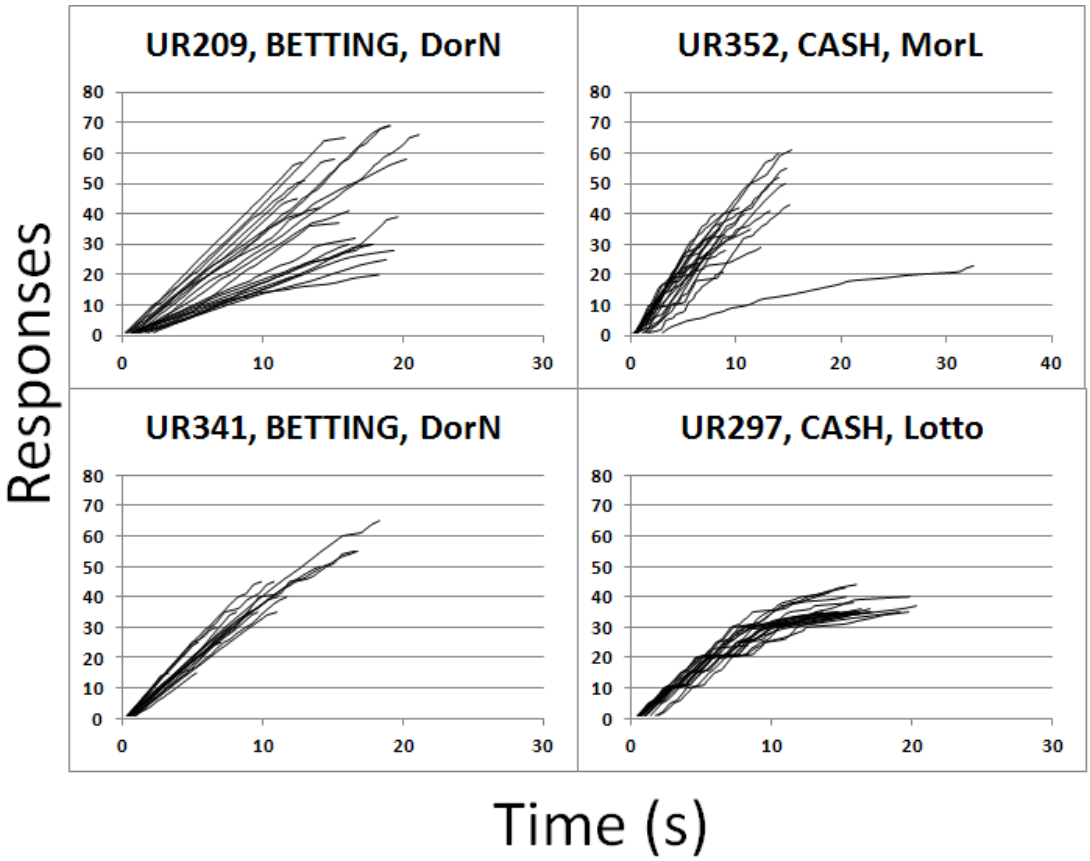

Figure 7. Cumulative response runs for the 30 balloons of 4 selected subjects; each line corresponds to a single balloon. For risk takers (Betting, Left Panels), responding during unexploded balloons was often characterized by a high steady rate followed by a decrease in response rate right before cashing points to the permanent bank; conversely, for non-risk takers (Cash, Right Panels), responding within balloons was often characterized by alternating periods of higher and lower rates, and a lower average number of responses per unexploded balloon. The observed patterns were not exclusive to one group or the other; most subjects showed a combination of both.

designed the choice tasks to assess the impact that features other than the average payoff (which was constant) might have on the probability of making the risky choice. The tasks differed on a number of dimensions including participant familiarity with the

game, randomization scheme (coin flip, sealed envelopes, and bingo cage), amount of largest possible prize ($10 or $15), and number of possible outcomes (2, 3, or 4). Based on our data it is not possible to determine how specific combinations of such features might have contributed to the participants' choice to bet. Further research is necessary to identify the specific contribution of the various functional components of the choice tasks. However, our results show that a number of contextual variables in the choice situation can affect the degree to which the total score obtained on the BAT predicts risky choice.

The cash prizes awarded in this study were relatively small. Using larger prizes for choosing the uncertain option while keeping the guaranteed prize constant may have the effect of increasing the percentage of subjects choosing to bet, as suggested by our results on the Lottery choice and, more generally, the observed relationship between state lottery ticket sales and jackpot size (DeBoer, 1990; Lyons & Ghezzi, 1995). Alternatively, increasing the guaranteed and uncertain prizes proportionally may decrease risk-taking among all subjects, and to a larger extent among those with the lowest BAT scores, as suggested by Bornovalova and colleagues (2009). A limitation of this study is that our sample of college students is not representative of the general population in terms of age, ethnicity, income, or education level. In conjunction with the magnitude of the prizes used, these factors may differentially affect the proportion of individuals choosing to gamble (Pietras & Hackenberg, 2001). Also, because we were interested in using the actual choice made by individual participants as independent variable in the analysis of response patterns in the BAT (i.e., risk takers vs. non-risk takers), presentation of the two tasks was not counterbalanced between subjects in this study. Therefore, the extent to which exposure to the BAT might have primed the subsequent choice for guaranteed or uncertain cash is unknown. Our results, however, are congruent with a large number of studies showing that BART scores significantly correlate with risk taking behavior measured at times and in situations where priming effects are not a concern. In addition, when we used the top and bottom quartiles of the distribution of BAT scores to identify risk takers and non-risk takers *independently* of their subsequent choice, we found results similar to those observed when the classification of individuals was based on their choice to bet or not to bet.

Analyzing the patterns of responding observed in the BAT revealed important differences in behavior that were not evident at the more molar level. As a group, risk takers made more pump responses and pumped longer per balloon than non-risk takers. These differences are naturally congruent with the BAT's overall risk scores. On the other hand, for both groups response times were shorter after experiencing an explosion than after saving points to the bank. These results are congruent with those observed earlier (Delfabbro et al., 1999; Dickerson et al., 1992; Dillen & Dixon, 2008; and Schreiber & Dixon, 2001) on placing slot machine bets. Dillen & Dixon (2008) and Schreiber & Dixon (2001) suggest that the shorter wait following loses might be related

to the aversive nature of the loss situation compared to the more positive valence of the winning situation; in other words, that the shorter RTs after loses indicate escape from a situation associated with aversive stimuli. We believe our results are consistent with that interpretation as well as with earlier research on escape from conditioned aversive stimuli (Libby, 1976).

Throughout the session, subjects in both groups showed evidence of learning, as previously noted by others (Lejuez et al., 2002; Jackson et al., 2013; Pleskac & Wershbale, 2012; Wallsten, Pleskac, & Lejuez, 2005). The mean number of responses per balloon exponentially increased during the first two thirds of the session, and remained asymptotic during the last third, substantially below the expected optimal 64 responses per balloon. Given that responding remained flat during a substantial portion at the end of the session, it is not clear if increasing exposure to the task by raising the number of balloons might eventually bring responding closer to optimality for either group. It is likely, however, that the maximum number of responses as well as the response rate at the asymptote might be affected by the specific explosion values programed in the session. In this study, the average programed explosion point was 64 pumps (same as Lejuez et al., 2002); however, because our interest was in assessing the effect of individual explosions on subsequent responding, we constructed the series of values so that 20% of the explosion points were at 7 pumps or less. As suggested by Thaler and Johnson (1990), it is possible that the number of explosions experienced after a short number of responses might have a substantial effect on the total number of responses in the session, and that more symmetric burst value distributions might lead to a higher number of adjusted responses per balloon.

In this study the points that participants earned playing the BAT did not have monetary value. Thus, another possible explanation for the suboptimal responding observed is that earning points was not powerful enough an incentive to sustain optimal responding. While motivational factors may have contributed to the observed level of responding, it is worth noting that studies where each response was followed by cash (e.g., Bornovalova et al., 2009; Lejuez et al., 2002), have also resulted in levels of responding bellow the expected optimal. Further research on the effects of length of exposure to the task, and the proportion and distribution of explosions in the session may shed light on the determinants of suboptimal responding across groups. Nevertheless, because the BART is an instrument designed to measure risk taking, generating average levels of responding roughly midway between zero and the optimal 64 responses per balloon is a highly desirable quality, as it allows for deviations at either side of the mean.

An important assumption in much of judgment and decision making research has been *human rationality*; that individuals attempt to maximize expected utility, and that this is occurs irrespective of external contextual variables. In the present experiment, responding was systematically affected by the occurrence of explosions and

by the number of successive unexploded balloons in both groups. Immediately after an explosion, the level of responding for both groups appeared to return to an intermediate level. Then, risk takers increased responding with every unexploded balloon, while non-risk takers decreased responding with every consecutive unexploded balloon. This recurring pattern of responding in relation to positive and negative outcomes strongly contributed to the overall quantitative differences in risk taking measured by the BAT. Generally, the BAT rewards risk taking up to a point, and risk takers generally earn more points in the game than non-risk takers. However, it is difficult to interpret the diverging patterns observed after explosions exclusively in terms of assumed reinforcing and punishing effects of points and explosions because those individuals that responded more and obtained the most points were also the ones experiencing the most explosions. In turn, those individuals that responded the least also experienced fewer explosions. While, as discussed above, there is clear evidence of adaptation to the consequences experienced in the BAT, the differential rates of responding observed between risk takers and non-risk takers appear to depend at least partly on the subjects' differential sensitivity to wins and loses under similar circumstances.

Within-balloons, two consistent cumulative patterns of responding were observed: a variable rate wavy pattern more typical of non-risk takers and a constant high rate pattern with a characteristic decline nearing the run's end, more frequently observed in risk takers. These patterns may indicate varying levels of attention, emotion, or perceived risk by the subjects. Observing participants respond gives one the impression that they are being more cautious or tentative when they slow down, as one would be when inflating a real balloon. Similar patterns had been reported earlier by Pleskac & Wershbale (2012), who proposed that the wavy pattern of responding occurs early in the session when subjects make more *evaluations* of risk in the situation, and that it evolves into the faster more *automatic* responding seen at by the end of the task. Our study shows, however, that these patterns were consistently associated with individual differences in risk taking throughout the session. We believe that the slower wavy pattern observed within balloons does reflect the more frequent appraisal of the situation that characterizes individuals who tend to make more conservative choices, and which is infrequent and localized in risk takers. Simultaneously, as described earlier, it seems that subjects in both groups adapt by exponentially increasing responding throughout the session.

Lejuez's BART was designed to provide a context in which individuals might reveal their propensity to make risky choices in real life. The evidence amassed so far indicates that the predisposition for risk-taking measured by the BART strongly correlates with other behavioral and self-report measures of impulsivity and risk taking. In addition, balloon analogue tasks can serve as experimental models to investigate individual determinants of risk-taking in the laboratory. The results presented here, for

example, show that the higher number of pumps and exploded balloons that characterize risk takers at a molar level, result from particular forms of adaptation to the positive and negative outcomes of risk taking behavior seen at a more molecular level; to our knowledge, this is the first study to show such effects. Further research may shed light on how genetic, neurological, historical, and environmental factors contribute to produce the observed recurrent patterns of risky choice.

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