



A Functional Analysis of Behavior in the Balloon Analogue Task ¹

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Abstract

In the balloon analogue task, a continuous schedule of positive reinforcement and a random ratio schedule of punishment for “pump” responses operate simultaneously, along with the opportunity to terminate each trial and avoid an impending punishing stimulus. In this study, the functional properties of game points and point losses were analyzed in three groups of college students (N=92) by varying the density of balloon explosions throughout the 30-balloon session. The within-session changes in density of explosions produced immediate systematic adjustments in pump responses per balloon. The results showed that 1) the number of pumps per balloon is sensitive to the local probability of explosions; 2) the suppression brought on by explosions depends on the temporal distance to the last explosion and the number of consecutive explosions; 3) suppression appears to be non-linear, with stronger effects as the local probability of explosions increases; and, 4) within limits, points without assigned extrinsic value may serve as reinforcers in the balloon analogue environment for populations with a history of game playing. Given these findings, a valuable strategy for future research may be to study differential reactivity to wins and losses as a proximal determinant of total scores that is amenable to experimental analysis.

Keywords: *Risk taking, functional analysis, balloon analogue, punishment, choice*

Resumen

En la tarea análoga de globos, un programa continuo de reforzamiento positivo y un programa de castigo de razón aleatoria operan simultáneamente, a la vez que existe la oportunidad de terminar cada ensayo y de esa forma evitar el estímulo aversivo programado. Con tres grupos de estudiantes universitarios (N=92), se analizaron en este estudio las propiedades funcionales de la ganancia y pérdida de puntos, mediante la manipulación de la densidad de explosiones de los globos (N=30) durante la sesión. Tal manipulación produjo ajustes inmediatos y sistemáticos en la tasa de respuestas de bombeo por globo. Los resultados mostraron que 1) el número de bombeos por globo es sensible a la probabilidad local de explosiones; 2) la supresión producida por las explosiones depende de la distancia temporal a la última explosión y del número de explosiones consecutivas ocurridas; 3) la supresión parece no ser lineal, siendo más severa a medida que aumenta la densidad de explosiones; y 4) dentro de ciertos límites, los puntos sin valor externo pueden servir de reforzadores para individuos con experiencia en jugar juegos por puntos. Dados estos hallazgos, es posible que investigar el efecto de la reactividad diferencial a ganancias y pérdidas como una causa próxima de los puntajes totales que es factible de análisis experimental, pueda ser una estrategia útil para la investigación futura en esta área.

Palabras Clave: *Toma de riesgo, análisis funcional, tarea análoga de globos, castigo, elección.*

¹ Reference to this article on the web is: <http://conductual.com/content/functional-analysis-behavior-balloon-analogue-task>

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Risk taking behavior is characterized by the pursuit of opportunities for gains that simultaneously involve some probability of loss; economic or otherwise. In that general sense, much of what humans do involves risk taking; getting up in the morning, driving to work, crossing a busy intersection, buying a lottery ticket, are but a few examples. While in most common situations the amount of risk involved is acceptably low, and most of us learn to control the amount of risk we take, it has been shown that excessive risk taking is often associated with serious clinical problems. Specifically, those with a higher propensity to take risks are more likely to experience injuries (Cherptel, 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).

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). A well-known laboratory model to estimate propensity for risk taking is the Balloon Analogue Risk Task (BART) developed by Lejuez and collaborators (2002). The BART is a computer 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 cash in a temporary bank. With every pump there is also a chance for loss, as each pump press can cause the balloon to explode. If the balloon bursts before the player saves these earnings, they are lost and a new trial begins. To prevent losses, the player can save the earnings in a permanent bank at any point before the balloon bursts. But such action also deactivates the current balloon and starts a new trial. The BART yields a scale-free total score equal to the mean number of pump responses in unexploded balloons; higher scores indicating higher propensity for risk taking. Also indicative of risk taking is the proportion of exploded balloons in the session.

The BART's external validity has been documented in a large number of studies. Total scores have 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 behavior (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 choices in other laboratory tasks (Mishra & Lalumière, 2010; Reynolds et al., 2006; Robles et al., 2014).

The assessment of risk taking. The balloon task estimates real-life propensity for risk taking by presenting subjects in the laboratory with multiple opportunities to respond under contingencies that resemble real life; thus the term *analogue*. The particular qualities that individuals bring to the test situation, in interaction with the consistent balloon task environment, result in differences in behavior and, hence, risk taking scores. Subject factors that are known to predict risk taking include age (Balogh, Mayes, and Potenza, 2013), gender (Aklin et al., 2005; Lejuez et al., 2002), trait impulsivity (Lejuez et al., 2002), IQ (Lejuez et al., 2002), substance use (Aklin et al., 2005; Crowley et al., 2006; Lejuez et al., 2002; Hopko et al., 2006), and delay discounting rate (Reynolds et al., 2006), among others.

Functionally, the balloon analogue task is similar to procedures used in the operant study of punishment (e.g., Azrin, Holz, & Hake, 1963), where an operant baseline is maintained by positive reinforcement (in this case cash gains) to which an intermittent schedule of punishment is added (in this case cash losses). In the balloon analogue, a second (*collect*) response is also available that terminates the trial, secures the earnings, and avoids presentation of the impending punishing stimulus. Because the task



runs for a fixed number of balloon trials (typically 30), ending a trial also carries some opportunity cost, as in order to maximize earnings, individuals must obtain as much cash per balloon as possible before terminating the trial. Therefore, it is the point at which the collect responses occurs that leads to differences in risk taking scores estimated by the BART. While it is still unclear exactly how individual differences in gender, personality traits, addiction status, and other variables contribute to determine BART scores, some studies (e.g., Ashenhurst et al., 2014; De Martini et al., 2014; Robles et al., 2014), suggest that differential reactivity to appetitive and aversive stimuli may be a central part of the answer.

A number of formal models have been proposed to predict performance on the balloon analogue task that incorporate parameters for sensitivity to wins and losses (Ashenhurst et al., 2014), alcohol dependence (Ashenhurst et al., 2014), genetic makeup (Mata et al., 2012), performance patterns (Wershbaile & Pleskac, 2010), and cognitive decision making processes assumed to underlie risk taking (Bishara et al., 2009; Wallsten, Pleskac, & Lejuez, 2005). Overall, these models find that, while modulated by characteristics of the subject, responding in the balloon analogue involves a balance between risk and reward. These models have been constructed on the basis of responding during the standard balloon analogue task without directly manipulating the level of risk and reward, or directly addressing local probability of balloon explosions as a central controlling variable. We believe that learning how the pump and collect responses are influenced by the contingencies of reinforcement programmed in the balloon analogue task may be germane to understanding risk taking behavior generally. Therefore, we suggest that a functional analysis of the stimuli and responses formally defined in the balloon analogue task might contribute to our understanding of choice in risky environments. The purpose of this study was to directly assess the relationship between earnings, balloon bursts, and pump responding in the balloon analogue task.

Method

Subjects

The participants (N=92) were 66 female and 26 male college students with a median age of 22 years. The gender distribution of the sample matched that of the student population. The volunteers were recruited through the departmental research subject pool and received class credit for participating in the study. Upon arrival to the laboratory, they were asked to seat at a computer station where their consent to participate was assessed. All study methods were approved in advance by the local Institutional Review Board.

Setting

The experimental sessions were conducted in a large, air conditioned, well illuminated laboratory. The three computer stations were set on desks facing the wall 2 m apart in such a way that participants completing the session at the same time could not directly see another participant's screen. All data were collected on 1.9 GHz laptop computers running Windows 7. A computer mouse attached to each machine was used to record all responses.

Procedure

Participants were randomly assigned to one of three groups differing on the local distribution of balloon burst values (see below), and then asked to complete the assigned version of a 30-trial balloon analogue task.



Figure 1. Main screen of the balloon analogue task.

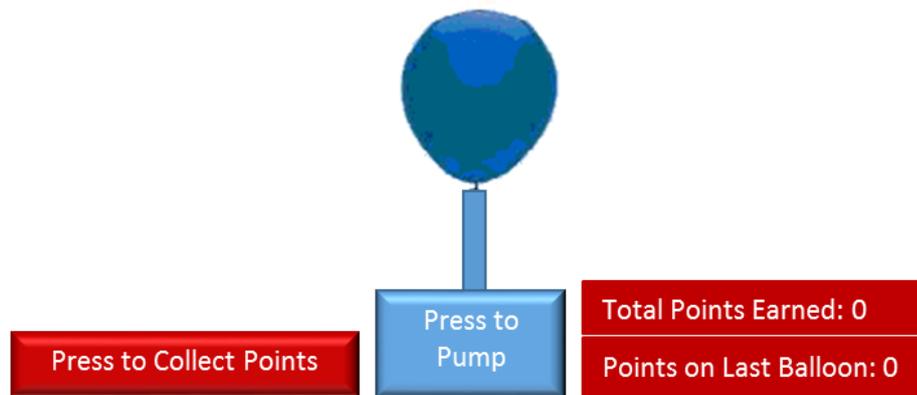


Table 1. Mean explosion points and probability of explosions by group, and the corresponding observed percentage of explosions and responses per balloon.

| First 10 Balloons | Probability of Explosion | | |
|-------------------------------------|--------------------------|----------|--------|
| | Low | Constant | High |
| Mean Explosion Point (Responses) | 105.00 | 64.00 | 24.00 |
| Nominal Probability of Explosion | 0.0095 | 0.0156 | 0.0417 |
| % Exploded Balloons | 16.88 | 24.33 | 41.67 |
| Mean Adjusted Responses per Balloon | 50.22 | 23.81 | 14.35 |
| Last 20 Balloons | | | |
| Mean Explosion Point (Responses) | 44.00 | 64.00 | 84.00 |
| Nominal Probability of Explosion | 0.0227 | 0.0156 | 0.0119 |
| % Exploded Balloons | 41.09 | 26.88 | 9.33 |
| Mean Adjusted Responses per Balloon | 25.43 | 28.97 | 32.94 |

Balloon Analogue Task

The version of the balloon analogue task used in this study is similar to the task described by Lejuez et al. (2002) with the exception that subjects played for points instead of cash, and that for two of the experimental groups the determination of the explosion points was modified as described below. In this computer simulation the image of a deflated balloon appears at the center of the computer screen (see Fig.1). Available to the subject are two response buttons. Clicking on one button (pump) increases the balloon size by a constant amount and adds one point to the subject’s temporary earnings; clicking this button also makes the balloon burst after 64 pumps, on average ($p = .0156$). If a balloon bursts, the points earned on that balloon are lost and the trial ends. Otherwise, pressing the second button (collect) at any time before a balloon bursts transfers the temporary earnings on the current balloon to a permanent bank where they cannot be lost, and terminates the trial. A new trial begins after a 2 s ITI with the presentation of a deflated balloon. Responses during the ITI have no consequences. There were 30 balloon trials in the session. For each subject, the individual balloon burst points were randomly selected without substitution from the following normally-distributed series: 1, 6, 11, 16, 21, 26, 31, 36, 41, 46, 51, 56, 61, 62, 64, 64, 66, 67, 72, 77, 82, 87, 92, 97, 102, 107, 112, 117, 122, 127. The burst point is the sequential number of the response that causes the explosion. For two of the groups, the burst points of the first 10 balloons were selected randomly from either the ten smaller (1, 6, 11, 16, 21, 26, 31, 36, 41, 46) or ten larger (82, 87, 92, 97, 102, 107, 112, 117, 122, 127) values in the series, while the remaining values applied to the last 20



balloons of each group; Table 1 shows the actual mean explosion points and probability of explosion by group for the first 10 and last 20 balloons in the session. Thus, while the session's overall probability of burst was constant across groups at 1/64, for the high-probability group (High; $N = 32$) a burst during the first 10 trials occurred after 24 pumps ($p = .0417$) on average and after 84 pumps ($p = .0119$) thereafter. And for the low-probability group (Low; $N = 30$) a burst during the first 10 balloons occurred after 105 pumps ($p = .0095$) on average and after 44 pumps ($p = .0227$) thereafter. For the third group (Constant; $N = 30$), values were selected from the full series and the probability of a burst remained constant at .0156 throughout the session. The main screen of the program also depicted two counters, one for the number of points earned on the last unexploded balloon, and a running counter showing the total points earned throughout the session. The points earned during the current balloon were not shown. The goal of the task was for the participant to earn as many points as possible; the points had no extrinsic value.

The following instructions were presented on the computer screen:

How to play:

- In this game you will get 30 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 to enough pumps to make the balloon fill the entire screen.
- You decide how much to pump up each balloon before you cash the points.

Data Analysis

The primary dependent variable was the number of responses emitted during unexploded balloons, also referred to as *adjusted responses* or *adjusted pumps* (these will be treated as synonyms), which constitutes the primary measure of risk taking in the BART (Lejuez et al., 2002). The general strategy of the study was to keep constant the overall probability of explosions for all groups at 1/64 (as in Lejuez' original BART study), and vary the local density of explosion for two groups. We assumed that by keeping constant the number of points per response (CRF), variations in the probability of explosions might lead to a differential number of pump responses at each programmed explosion density. In the following section we describe the effects of the experimental manipulation on responding a) over the entire session,



b) across successive balloons, c) as a function of temporal proximity to one or more bursts, and d) as a function of the local probability of balloon bursts. In the analyses that involved balloons in a sequence, *balloon number* refers to its position in the 30-balloon session. The balloon analogue program was written in Visual Basic 6.0; Visual Fox Pro 9.0 and Excel 2013 were used to prepare data files and charts, and IBM SPSS v22.0 was used in the statistical analyses.

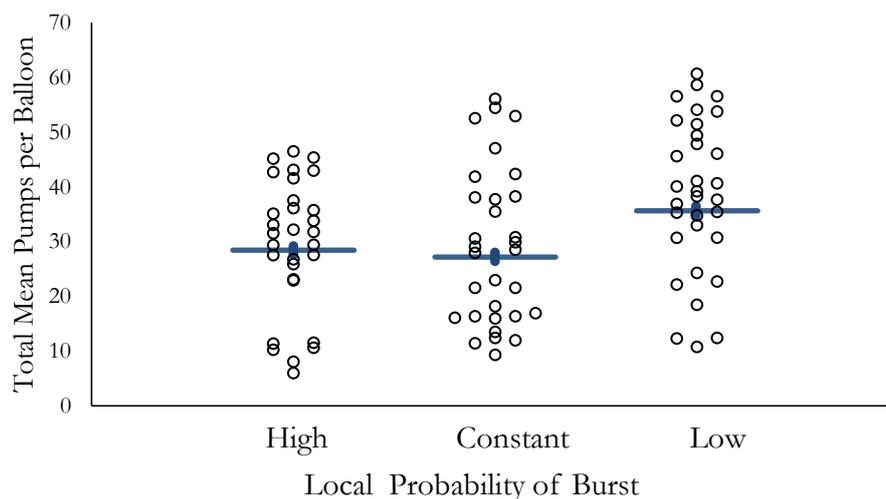
Results

All the volunteers who registered to participate in the study completed the balloon analogue task. The instructions on how to play the balloon analogue, along with the response-contingent game points, were sufficient to maintain adequate levels of responding in all participants.

Total Scores

The mean number of pump responses in the session occurring during unexploded balloons is shown in Figure 2. Symbols represent individual scores and lines show group means and standard errors. The figure shows that the spread of the resulting group distributions was inversely related to the probability of burst during the first 10 balloons. In addition, a one-way ANOVA revealed significant differences in total scores between the groups ($F(2, 89) = 4.61, p < .02$), and post hoc comparisons showed that the Low burst probability group emitted more responses per balloon than the other two groups (both $p < .05$). Table 2 shows descriptive statistics for total scores by group. The average number of pump responses per balloon (High = 28.41; Constant = 27.21; Low = 35.69) was not far from the 28 obtained by Lejuez et al. (2002), and close to half of the optimal 64.

Figure 2. Individual mean adjusted pumps per balloon in the session. The total number of pumps per unexploded balloons in the session was significantly higher for the low burst probability group compared to the other two. The symbols represent individual scores and the lines show group means and standard errors.



The individual proportion of exploded balloons in the BART correlates highly with the total score and it is an accepted (Lejuez et al., 2002) indicator of propensity for risk taking; this was also true for our results ($\rho = .889$). In this study, a difference in the proportion of exploded balloons by group could indicate that the number of pumps responses was limited by the number of explosions occurring in the High burst probability group; however, a comparison of the exploded balloons in the session by group shows that was not the case. Table 1 shows the explosion points, probability of explosions, and mean number of pumps per balloon during the first ten and last 20 balloons in each group. Note that while the



optimal number of responses per balloon during the first 10 balloons for the High burst probability group was 24 responses, the observed rate was 14.4 responses; 40% below the limit.

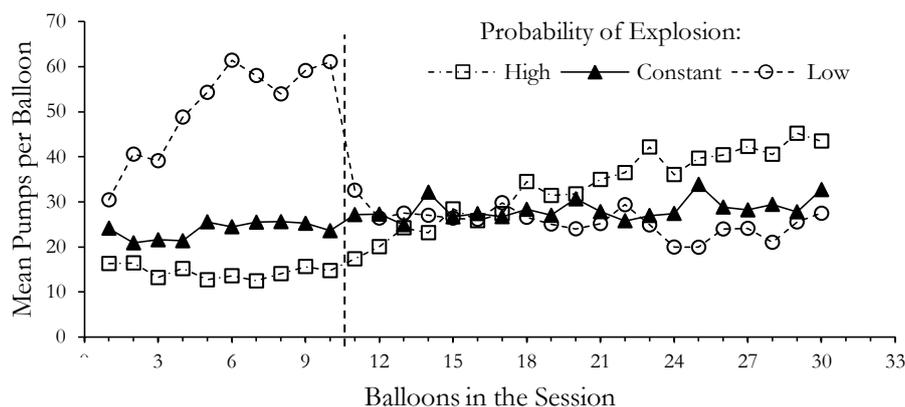
Table 2. Descriptive statistics by probability of explosion during first 10 balloons.

| Group | Mean | Std. Deviation | Std. Error | 95% Confidence Interval | |
|----------|-------|----------------|------------|-------------------------|-------|
| | | | | Lower | Upper |
| Low | 35.69 | 26.00 | 0.86 | 34.01 | 37.37 |
| Constant | 27.21 | 18.75 | 0.84 | 25.56 | 28.86 |
| High | 28.41 | 20.02 | 0.81 | 26.82 | 30.00 |

Throughout the Session

Figure 3 shows the mean number of adjusted pump responses per balloon throughout the session by group. Differences in the probability of balloon bursts were inversely related to responding during the first 10 balloons. For the Low probability group responding increased over the first six trials to around 60 pumps per balloon. Then, a rapid adjustment toward the middle occurred when the probability of burst increased at the 11th balloon, followed by a more gradual adjustment to local burst densities over the remaining 20 balloons. For the High burst probability group, responding was the lowest during the first 10 balloons, and increased gradually thereafter, as would be expected on the basis of the local distribution of burst values remaining. In turn, the Constant probability group, which experienced invariant burst density, was characterized by a much less noticeable steady increase in responding throughout the session.

Figure 3. Mean pump responses per unexploded balloon by group. Over the entire session, balloons were programmed to burst after 64 pump responses, on average ($p = .0156$) for all groups. However, during the first 10 balloons (left of the dotted line) the local probability of explosion was preset for two groups (Low and High), and remained consistent throughout for the third group (Constant).



Proximity to Explosions

Figure 4 shows the effect of the number of consecutive balloon bursts on responding on the 12 contiguous unexploded balloons after the last burst. The effect is shown as mean proportion of individual subjects' session average number of responses in unexploded balloons. Note that the number of times when 1, 2, and 3 or more explosions occurred contiguously over the session for each subject, as well as the number of unexploded balloons between explosions were a function of the randomly selected



explosion values and the individual subject's behavior. Therefore, the reported mean values were based on a variable number of cases. Only data for the first 12 consecutive unexploded balloons after a burst were used in the calculations because the number of cases where series of more than 12 consecutive unexploded balloons occurred was too small to be statistically meaningful. Table 3 shows the complete dataset with number of cases and mean proportion of pumps for all the observed series of unexploded balloons in the study (N = 1, 693). Figure 5 shows the same data shown on Figure 4 collapsed across number of explosions; the number of cases used in these calculations is shown in the right-most column of Table 3. Together, these figures show that balloon bursts had a clear suppressive effect on subsequent responding, and that the effect was proportional to the number of back-to-back explosions. Immediately after a burst the number of pumps decreased by an average of 25%. Then, over the next 12 contiguous unexploded balloons, pump responses recovered and exceeded individual subjects' session means. For all subjects, a linear regression model accounted for 82% of the variance in responding during the 12 balloons following a burst ($p < .0001$). Because this analysis was performed using all available data a remaining question is whether the effects observed might be an artifact of averaging data from the High and Low burst probability groups. To address this issue we ran the same analysis on the data from the Constant group only. A similar suppression and recovery of responding after explosions was observed. A linear regression model of the proportion of individual means over the five balloons following an explosion for the Constant group accounted for 95% of the variance ($a = .81, \beta = .063; p < .01$), corroborating the results obtained with the full dataset.

Figure. 4. Effect of 1, 2, and 3 or more contiguous balloon bursts on the mean number of pumps in succeeding unexploded balloons for all subjects.

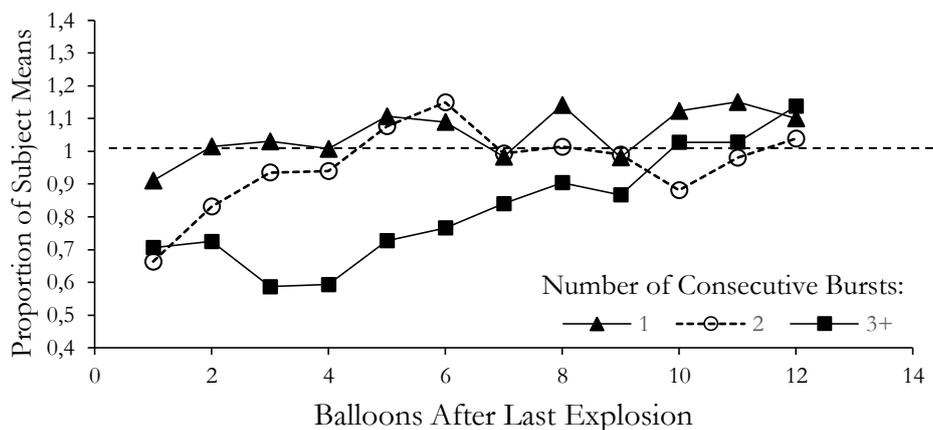


Figure. 5. Effect of balloon bursts on the mean number of pumps during succeeding balloons throughout the session for all subjects.

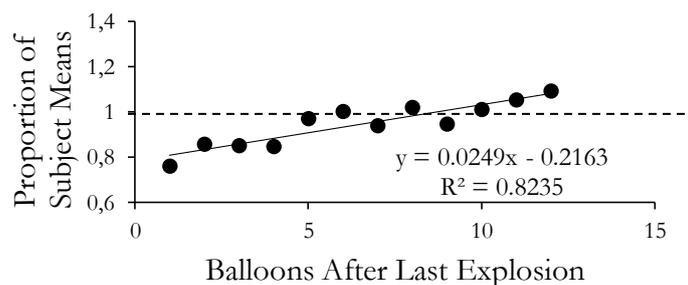




Table 3. Number of times 1, 2, and 3 or more explosions occurred contiguously during the session and the corresponding change in pump responses (as proportion of subject means) over succeeding unexploded balloons.

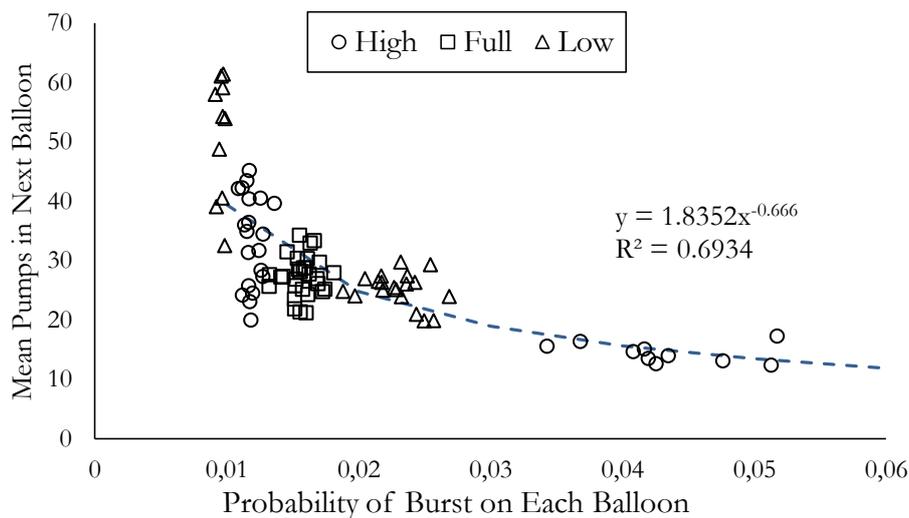
| Balloons After Last Burst | After 1 Burst | | After 2 Bursts | | After 3+ Bursts | | Total Number of Cases |
|------------------------------------|--------------------|----------------------------------|--------------------|----------------------------------|--------------------|----------------------------------|-----------------------------|
| | Number of Cases | Proportion of Session Mean | Number of Cases | Proportion of Session Mean | Number of Cases | Proportion of Session Mean | |
| 1 | 312 | 0.911 | 123 | 0.663 | 40 | 0.706 | 475 |
| 2 | 208 | 1.015 | 80 | 0.832 | 23 | 0.725 | 311 |
| 3 | 140 | 1.030 | 54 | 0.936 | 15 | 0.587 | 209 |
| 4 | 88 | 1.007 | 37 | 0.940 | 10 | 0.593 | 135 |
| 5 | 62 | 1.107 | 28 | 1.077 | 9 | 0.727 | 99 |
| 6 | 44 | 1.090 | 19 | 1.150 | 7 | 0.766 | 70 |
| 7 | 38 | 0.983 | 10 | 0.993 | 7 | 0.840 | 55 |
| 8 | 33 | 1.141 | 8 | 1.014 | 6 | 0.904 | 47 |
| 9 | 26 | 0.981 | 7 | 0.990 | 5 | 0.867 | 38 |
| 10 | 21 | 1.123 | 5 | 0.881 | 5 | 1.028 | 31 |
| 11 | 18 | 1.150 | 5 | 0.981 | 5 | 1.028 | 28 |
| 12 | 16 | 1.100 | 5 | 1.039 | 5 | 1.138 | 26 |
| 13 | 14 | 1.2768 | 5 | 1.1118 | 4 | 1.1195 | 23 |
| 14 | 14 | 1.1424 | 5 | 1.163 | 4 | 1.3177 | 23 |
| 15 | 13 | 1.4035 | 5 | 1.1488 | 4 | 1.3445 | 22 |
| 16 | 12 | 1.4651 | 5 | 1.1326 | 4 | 1.4274 | 21 |
| 17 | 12 | 1.5629 | 4 | 1.293 | 2 | 1.2015 | 18 |
| 18 | 10 | 1.3936 | 4 | 1.3269 | 2 | 1.602 | 16 |
| 19 | 8 | 1.3198 | 4 | 1.6085 | 2 | 2.1733 | 14 |
| 20 | 7 | 1.3924 | 4 | 1.9689 | 2 | 1.9599 | 13 |
| 21 | 5 | 1.459 | 2 | 1.361 | 1 | 1.9827 | 8 |
| 22 | 2 | 1.4044 | 2 | 1.6538 | 0 | -- | 4 |
| 23 | 1 | 1.9938 | 1 | 1.7666 | 0 | -- | 2 |
| 24 | 0 | -- | 1 | 1.8549 | 0 | -- | 1 |
| 25 | 0 | -- | 1 | 1.8549 | 0 | -- | 1 |
| 26 | 0 | -- | 1 | 1.9432 | 0 | -- | 1 |
| 27 | 0 | -- | 1 | 2.0315 | 0 | -- | 1 |
| 28 | 0 | -- | 1 | 2.2082 | 0 | -- | 1 |
| 29 | 0 | -- | 0 | -- | 0 | -- | 0 |

Local Probability of Explosions

The effect of the observed local probability of bursts on mean adjusted pumps is shown on Figure 6. The chart depicts the relationship between the groups' mean number of adjusted pumps on each balloon in the session and the observed mean probability of burst for the preceding balloon. Note that for the Constant probability group (squares), all the data points are clustered around the center of the distribution, while for the Low (triangles) and High (circles) burst-probability groups the data points are clustered in two groups each, one for the first 10 balloons and one for the remaining 20. Overall, the number of pumps per balloon changed non-linearly across the various burst densities, with proportionally less suppression at the lower end. This relationship was adequately described by a negative power function ($R^2 = .69; p < .0001$).



Figure 6. Mean number of adjusted pumps per balloon as a function of the local (balloon-by-balloon) probability of bursting for all groups. A power model accounted for 69 % of the variance.



Discussion

These results show that behavior in the balloon analogue task was jointly controlled by the reinforcing and punishing stimuli contingent on pump responses. While the instructions provided, along with the earned game points, were sufficient to maintain adequate responding throughout the session in all subjects, balloon explosions had a clear suppressive effect on the number of pump responses in succeeding unexploded balloons, systematically affecting the point at which the collect responses were made. Responding over the session generally tracked the observed local density of balloon bursts. Subjects in the Constant probability group maintained a relatively flat level throughout; the slight increase in responding observed throughout the session may be a practice effect. In contrast, during trials 1 through 10, where the differences in burst probability were more extreme, the mean number of pumps per balloon for the High and Low groups differed increasingly between groups, and then converged toward the middle soon after the 11th balloon.

Long-lasting effects of the initial exposure to different burst densities were not evident. On the contrary, behavioral adaptation to changes in the local density of balloon explosions was swift, regardless of the initial group-specific conditions. Moreover, the suppressive effect of balloon bursts did not appear to be a linear function of burst probability. At least under the present experimental conditions, points earned on a continuous schedule of reinforcement had a relatively stronger effect than balloon explosions at lower compared to higher burst probabilities, resulting in a distribution that is best described by a power function. This deviation from linearity, sometimes referred to as *risk-aversion*, also partially reflects the additive suppressive effects that consecutive explosions had on responding and the additive reinforcing effects of points earned during consecutive unexploded balloons. Specifically, at a more molecular level, balloon explosions had suppressive effects that depended jointly on the temporal distance from the last explosion and the number of consecutive explosions in the series.

The speed with which behavior adapted to variations in the density of explosions is noteworthy. While it is common in basic and applied research to describe orderly behavior changes between sessions, the changes observed in this study occurred reliably between balloon trials of a single session. Although



pump responding in the balloon analogue occurs freely, the way in which the balloon ends (win/loss, reinforcement/punishment) appears to be the most relevant functional event determining future pump and collect responses. In the animal behavior literature, the work by Davison, Baum, and colleagues (Aparicio & Baum, 2006, 2009; Baum & Davison, 2004; Davison & Baum 2000; 2002; 2003; 2006; 2007; Landon & Davison, 2001; Landon, Davison & Elliffe, 2003) has clearly shown that, as expected, every reinforcer counts in determining future behavior. Using concurrent schedules with two variable interval components, these authors have observed that response allocation adjusts rapidly within each component to the reinforcement conditions active in that component, and that systematic *preference pulses* or intervals of higher local preference for the component providing the most recent reinforcer regularly occur. Such local preference dissipates over time and is influenced by further reinforcement on either component in a dynamic and systematic fashion. The present results demonstrate that a similar form of immediate dynamic adaptation to reinforcers and punishers occurs within a single balloon analogue task session.

The points that subjects earned in this study clearly functioned as reinforcers; yet, they had no assigned extrinsic value. Specifically, the instructions given to the participants stated that the goal of the task was to earn the most points without reference to any form of exchange, the class credit that participants received was known in advance and equal for all subjects, and the computer stations were arranged in such a way that subjects completing the task at the same time could not see each other's screens. It is unlikely, then, that the reinforcing power of the points might have derived from competition between subjects or confusion over some presumed form of exchange. Rather, it appears that for the population of college students in this study, who are likely to have a history of playing sports, cards, and video games involving points, instructions to respond served as a setting event (Dougher & Hackbert, 2000) that conferred reinforcing value to the points within the task. In most balloon analogue research, however, subjects receive cash for pump responses. It has been shown, for example, that the total number of adjusted responses in the BART is sensitive to the amount of money paid per response (Bornovalova et al., 2009), with subjects taking less risk as the magnitude of the gains and losses increases from 5 to 25 cents per response. While it can be safely assumed that contingent cash will function as reinforcer in most cases, it is not clear how far the parallel between cash and valueless points might be extended. For example, would increasing the number of points per response also lead to lower risk scores?

The functional analysis presented here accounts for the observed balloon-by-balloon differences in responding in the task. However, individual differences in estimated propensity for risk taking (i.e., the individual mean adjusted responses per balloon) remain to be fully accounted for. Specifically, in this study there was a 40- to 50-point span between the lowest and highest individual scores within groups. In the literature, such differences have been shown to correlate in various degrees with individual differences in gender, impulsivity, IQ, drug use, delay discounting rate, and other variables. But, at this point, it is not clear how those variables might causally relate to risk taking in the balloon analogue. Differences in risk taking as measured by the BART are quantitative, and a number of behavioral processes may lead to similar BART scores. Furthermore, such processes may vary depending on the particular comparisons we make. In other words, what makes a cocaine addict have higher BART score than a non-addict may be different from what makes men have higher BART scores than women, and so on. Some authors propose, for example, that alcoholics may take more risks in the BART because they are less sensitive to losses than non-alcohol dependent subjects (Ashenhurst et al., 2014; DeMartini et al., 2014). Following that reasoning, we could ask what might be responsible for the differences in scores observed between men and women (Aklin et al., 2005; Lejuez et al., 2002). It is possible, for example that some subjects' performance might be rule-governed and thus less sensitive to the contingencies of reinforcement in the task. It is possible that some subjects might focus on *preventing* explosions while others might focus on earning the most points, and that these different approaches may be responsible for different response



patterns. In turn, it is possible that such different controlling factors might be related to one or more of the individual differences associated with higher overall BART scores and specific subject variables.

One possible way to address these questions is to look at the response patterns within- and between balloons in the BART in relation to specific individual differences in gender, addiction status, delay discounting rate, and other pertinent variables. An earlier study from our laboratory found, for example, that subjects whose balloon analogue scores fall within the top third of the distribution tend to respond differently after explosions than subjects scoring in the lower third (Robles et al., 2014). Immediately after an explosion, subjects in the top third of the distribution show a reduction in responding that recovers monotonically over the following unexploded balloons. In turn, subjects in the lower third show markedly lower suppression over the following unexploded balloons. Also, studies on gambling (Schreiber & Dixon, 2001) and risk taking (Robles et al., 2014) have shown that the time to the first response in each balloon is significantly greater after wins than after losses, which may be related to the positive/aversive properties of the stimuli associated with each outcome. If these differences were due to the relative reinforcing and punishing strength of wins and losses, then it might be possible to directly evaluate the “insensitivity to losses” hypothesis proposed to explain the performance of alcoholics and other addicts on the BART.

The functional analysis performed in this study focused on the effect that points and explosions had on pump and collect responses. The general strategy was to maintain the session’s overall density of explosions equal for all groups while manipulating the local density of explosions for two groups and holding it constant for a third –control- group. The strategy appears to have been effective in isolating the effect of points and explosions on performance at the group level, but a similar analysis at the individual level might not be as revealing. Individuals vary greatly in response rate and pattern such that the results derived from individual subjects’ sessions are unlikely to contain enough data points to depict meaningful sections of the observed group distributions. In other words, it may not be possible, for example, to observe the systematic effects of balloon-by-balloon changes in density of explosions on individual subjects after a single balloon analogue task session. On the other hand, such variability between subjects may reveal valuable patterns of responding triggered by factors associated with differences in impulsivity or propensity for risk taking such as drug use or delay discounting rate, as suggested by Robles et al. (2014).

The present analysis did not address the discriminative function of the physical aspects of the stimuli and, in particular, the changes in size of the balloon image within the trials. Because the points earned on a given balloon are not shown until a trial ends, some subjects may count their pump responses or assess their performance within the trial based on the size of the balloon relative to the screen. It is possible that changes in the rate at which the balloon is inflated throughout the session may affect only some of the subjects, and that those who count responses may show different response patterns than those who don’t. Further research is necessary to expand this functional analysis to account for discriminative stimuli in the task.

In sum, this study showed that in the balloon analogue task the number of pumps per balloon is sensitive to the local probability of explosions; that the magnitude of suppression brought on by explosions depends both on the temporal distance to the last explosion and the number of consecutive explosions; that the magnitude of the suppression appears to be non-linear, with stronger effects as the local probability of explosions increases; and that, within limits, points without assigned extrinsic value may serve as reinforcers for populations with a history of game playing. Given these findings, a valuable strategy for future research may be to study differential reactivity to wins and losses as a proximal



determinant of total scores amenable to experimental analysis. Finally, these results contribute to the growing literature showing that the balloon analogue task is a valid and efficient model to study risk taking behavior.

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