Using the Balloon Analogue Risk Task (BART) to examine neural correlates of risk-taking behavior in adolescents

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Introduction

Adolescence is characterized by increased risk-taking behavior (Steinberg, 2008), which has been proposed to result from earlier development of the mesolimbic dopamine pathway implicated in reward (and emotion) processing in comparison to top-down prefrontal control systems (Casey et al., 2008). To date, most of the research on adolescent risk-taking behavior has relied on self-report methodologies which incur a number of challenges (e.g., response bias). The goal of the current study was to examine the neural mechanisms underlying decision making during risk (i.e., contemplation, anticipation, and reward) using a modified version of the Balloon Analogue Risk Task (BART).

The BART is a computer-based tool used to examine risk-taking behavior by having participants to blow up virtual balloons (Lejuez et al., 2002). Similar to real-world situations, riskiness during the task is rewarded up until a point at which further riskiness results in poorer outcomes. Previous research with young adults and typically developing adolescents has shown that riskiness on the BART is positively correlated with scores on established risk-related constructs (e.g., sensation seeking, impulsivity) as well as risk-taking behaviors in the domains of substance use (e.g., smoking), delinquency and safety (e.g., stealing, wearing a seat belt; Lejuez et al., 2002; 2007).

This task has been used previously in an adult sample to examine the neural correlates of risk taking (Rao et al. 2008). Activation in mesolimbic-frontal regions, including the midbrain, ventral and dorsal striatum, anterior insula, dorsal lateral prefrontal cortex (DLPFC), and anterior cingulate/medial frontal cortex (ACC/MFC), and visual pathway regions were associated with risk taking. Decision making was associated with neural activity in the right DLPFC.

Goals

- Examine neural mechanisms underlying decision making during risk in adolescence
- Separate risk taking into component parts: contemplation, action, anticipation, outcome
- Examine neural correlates of previous risks outcomes on future decisions

Methods

Participants

Participants included 27 (17 female, 10 male) 16- to 20-year-old African American adolescents who were participating in an ongoing study examining the effects of prenatal substance exposure and social risk factors on the neurocognitive and social development of teenagers from urban, low-income environments.

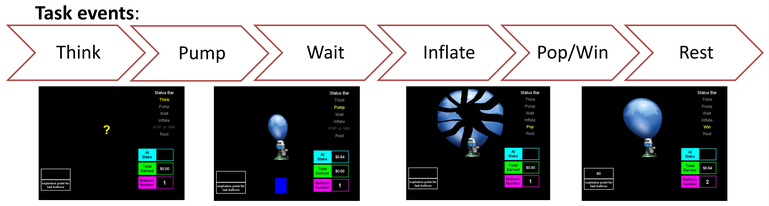
- Average age = 17 years +/- 16 months

BART

Participants record the number of pumps they would like to use to inflate the balloon (range 0-128).

- Each pump is worth $0.01 (i.e. 64 pumps are worth $0.64)
- Unknown explosion point
- If pumps exceed explosion point, balloon pops and no money is collected
- If pumps do not exceed explosion point, balloon inflates and money is "banked"
- "64 pumps is the best overall choice but it may not be the best for every balloon"
- Receive 20 balloons per block and complete 4 blocks
- Jitter 2-5 seconds at each task event

Task events:



fMRI Data Acquisition

- 3T Siemens TRIO scanner for whole brain BOLD EPI
- 39 oblique axial 4 mm slices, TR=2, TE=27ms, FOV=220mm, Matrix=64x64

fMRI Analysis

- Data spatially normalized, smoothed to 8 FWHM via AFNI
- Task events extracted: Think, Pump, Wait, Inflate, Pop, Win
- Two analyses
  - Task event activation: event versus averaged baseline
  - Effect of previous outcome : event-following-pop minus event-following-win
- Thresholded at voxel-wise p=0.005, cluster size = 50, corrected p<0.05

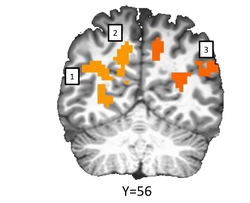
fMRI BOLD Activation

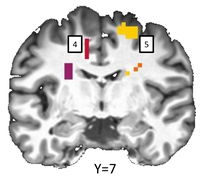
Task Event versus Baseline

All activation positive; colored by activation cluster (p<0.05)

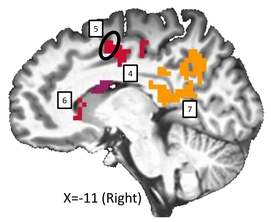
Standard Talairach coordinates (LPI); Left = Right

"Think" : Contemplation Phase

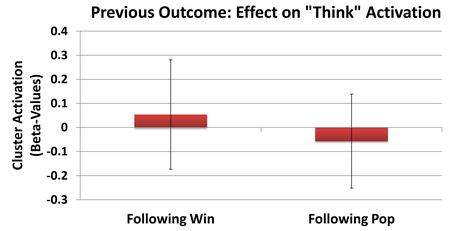




1. Middle Temporal
2. Precuneus
3. Superior Temporal
4. Cingulate Gyrus
5. Medial Frontal
6. Caudate
7. Posterior Cingulate

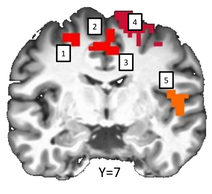


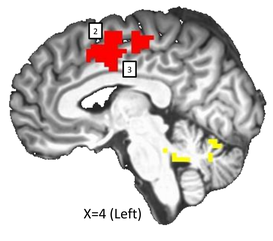
Previous Outcome: Effect on "Think" Activation



Previous trial outcome effect on "Think" overlaps with "Think"-versus-baseline map at Medial Frontal Gyrus (black oval). Graph indicates cluster activation for "Think"-Following-Win and "Think"-Following-Pop (error bars represent standard deviation).

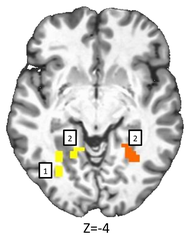
"Pump": Action Phase





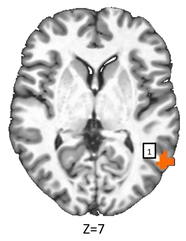
1. Middle Frontal
2. Medial Frontal
3. Cingulate Gyrus
4. Superior Frontal
5. Insula

"Inflate": Anticipation Phase



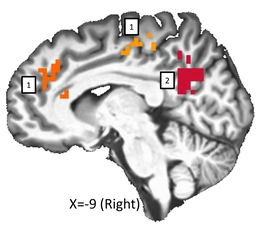
1. Fusiform Gyrus
2. Parahippocampal Gyrus

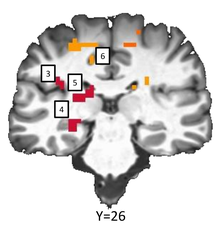
"Pop": Negative Outcome



1. Left Middle Temporal Gyrus

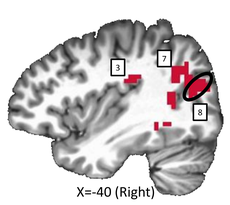
"Win": Positive Outcome

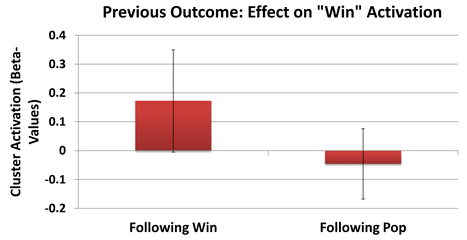




1. Medial Frontal
2. Precuneus
3. Insula
4. Parahippocampal
5. Thalamus
6. Cingulate Gyrus
7. Inferior Parietal
8. Middle Temporal

Previous Outcome: Effect on "Win" Activation





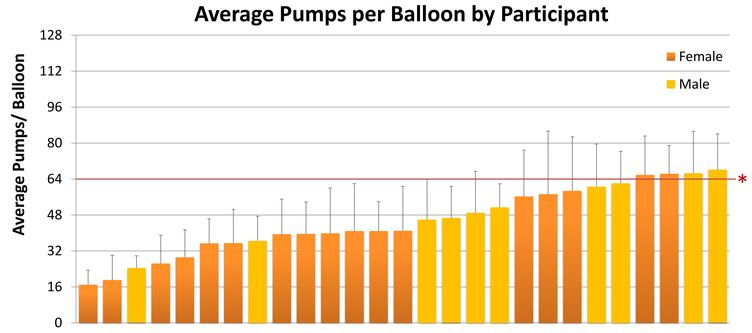
Previous trial outcome effect on "Win" overlaps with "Win"-versus-baseline map at Superior Temporal Gyrus (black oval). Graph indicates cluster activation for "Win"-Following-Win and "Win"-Following-Pop (error bars represent the standard deviation).

Behavioral Analysis

Variable	Minimum	Maximum	Mean +/- Std. Deviation	Gender Difference?
Average Pumps/Balloon	16.90	68.12	45.13 ± 14.97	p=0.122
Total Wins	36.00	59.00	49.41 ± 6.91	p=0.041 (M<F)
Total Pops	21.00	44.00	30.59 ± 6.91	p=0.041 (M>F)
Average Pumps/Win	16.31	66.50	41.80 ± 14.21	p=0.081 (M>F)
Average Pumps/Pop	18.57	71.15	50.37 ± 15.55	p=0.247
Pump Adjustment After Win	-9.30	9.60	1.75 ± 3.30	p=0.381
Pump Adjustment After Pop	-13.5	11.3	-3.29 ± 5.27	p=0.074 (M<F)

Males had significantly fewer wins and more pops than females. At trend level significance, males gave more pumps per winning balloon and adjusted less after a popping balloon than females.

Average Pumps per Balloon by Participant



Lowest-to-Highest Mean Pump Selection by Participant (n=27)

* Indicates pump choice participants are told is "the best overall choice but it may not be the best choice for every balloon"

Discussion

Conclusions

In terms of behavioral performance, adolescents' show a wide range of variability on the BART both within and between subjects. Individual mean pump selection was as low as 17 pumps and as high as 68 pumps. Despite no significant difference in the average pumps per balloon, males had more pops than females. These findings are consistent with previous reports of gender differences in task performance (see Lejuez et al., 2002) and point to adolescent males likely being more risk tolerant than adolescent females.

In terms of neural activation, the present task engaged posterior and medial frontal regions during the contemplation phase, frontal and insular regions during the action phase, fusiform and parahippocampal regions during the anticipation phase, and both medial frontal and temporal regions during the outcome phase. These regions are similar to those reported by Rao and colleagues (2008) using a different version of the task in adults (i.e. insula, mid-brain/thalamus, fusiform, parietal and anterior cingulate regions).

A novel "effect of previous trial outcome" analysis was conducted on the "Think" and "Win" task events. This ecologically-valid analysis mimics experience-based decision making. Trials following a "Win" versus a "Pop" produced more robust positive activation at both "Think" and "Win" task events. Activation overlapped with the "Think" event map at the medial frontal gyrus and with the "Win" event map at the superior temporal gyrus. The positive activation difference may be related to higher expectations following a positive outcome.

Future Directions

- Continue recruitment for larger sample size
- Analyze trials by "risky"/"safe" split on individual median pump choice
- Correlate performance on BART and associated neural activations with self-reported measures of real-world risk taking (e.g., Youth Risk Survey)
  - Lejuez et al (2003) found riskiness on BART positively correlated with scores of established risk-related constructs, such as impulsivity, and risk-taking behaviors, such as delinquency
- Examine the impact of variations in early life experience (e.g,. prenatal substance exposure, social risk factors) on activation patterns

References

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