vmPFC lesions impact the multi-attribute integration of decisions in opposite ways for delay and probability discounting

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Background

Delay and Probability Discounting

- Delay discounting (DD) describes the process by which an individual forgoes a larger reward obtained later in the future for a smaller reward that can be obtained immediately.
- Probability discounting (PD) describes the process by which an individual forgoes a smaller, more guaranteed reward for a larger, less guaranteed reward.[1]

Common mechanisms of reward discounting?

- Evidence suggests that a common mechanism underlies delay discounting and probability discounting, as both are:
  - described by hyperbola-like functions
  - conceptually similar in describing risk-taking (e.g., rewards available after longer delays are less certain than immediate rewards).
- Other findings, however, indicate that DD and PD respond in opposite ways to manipulations of reward amount and reflect independent traits.[1]

Engagement of decision-making in ventromedial prefrontal cortex (vmPFC)

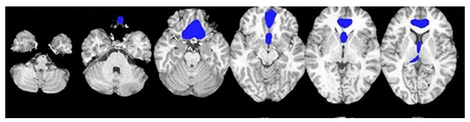
- vmPFC is necessary for encoding subjective values of different reward types and conditions. Patients with vmPFC lesions display short-sighted and risk-taking behaviours compared to healthy controls and to patients with lesions to the medial temporal lobe (MTL).[2-3]
- Previous research has examined the effects of vmPFC lesions either on intertemporal choice (delay discounting) or risky choice (probability discounting) but have not investigated these possibly related types of discounting together in vmPFC patients.

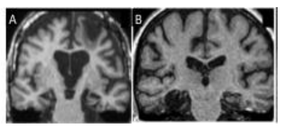
Research Questions:

- What relationship does vmPFC have with DD and PD? How does performance compare to that of healthy controls and MTL patients who show deficits in future imagining but often with intact discounting?
  - i.e., Does a single valuation mechanism underlie both intertemporal and risky choice?

Participants

Lesion	N (M:F)	Age (yrs ± SD)	Education (yrs ± SD)
VMPFC (ACoA)	8 (4:4)	56.0 ± 15.7	14.8 ± 2.3
MTL	11 (11:0)	57.4 ± 12.7	15.7 ± 2.4
Controls	30 (17:13)	60.5 ± 7.5	16.0 ± 2.3





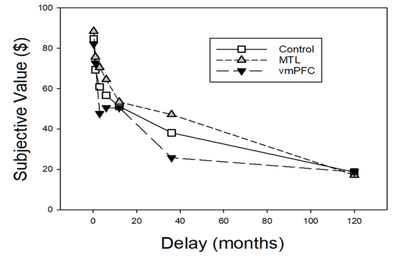
(TOP) MTL representative damage for two patients, **(A)** KC (62 M) and **(B)** DA (62 M)

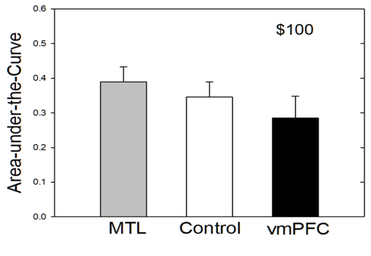
(LEFT) vmPFC participant representative damage for patient SB (43 M)

Experimental Design & Results

Delay Discounting Task

Participants were presented with hypothetical monetary values, and asked to choose between smaller, immediately rewards or larger, later rewards (e.g., "$1000 now or $2000 in 3 months?")





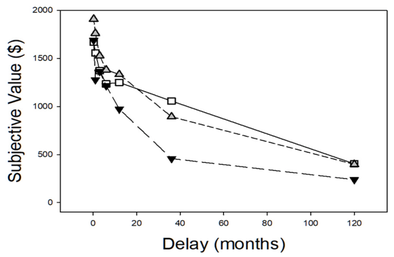


Figure 1. Subjective value as a function of delay of receiving the $100 or $2000 future reward amounts.

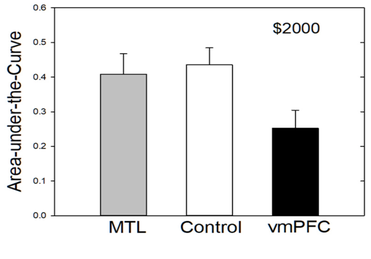
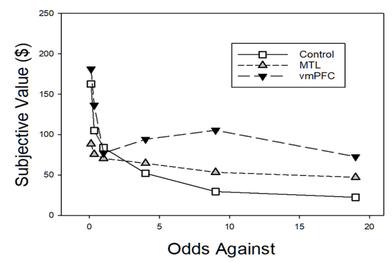
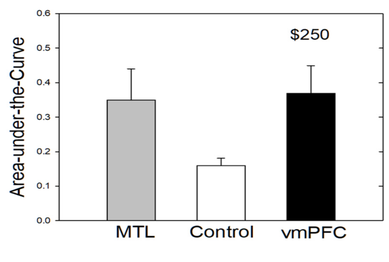


Figure 2. Area-under-the-curve mean values for vmPFC, MTL, and control groups.

Probability Discounting Task

Participants were presented with hypothetical monetary values, and asked to choose between smaller, guaranteed rewards or larger, probable rewards (e.g., "$1000 for sure or $2000 with a 75% chance of receiving?")





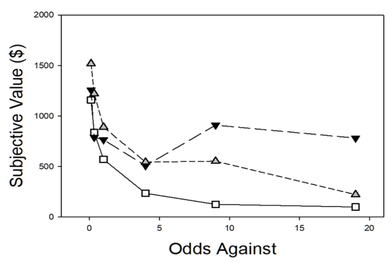


Figure 3. Subjective value as a function of odds against receiving the $250 or $2000 reward amounts.

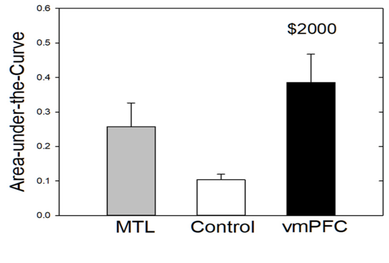


Figure 4. Area-under-the-curve mean values for vmPFC, MTL, and control groups.

Statistical Analyses

The extent to which participants discounted rewards was assessed using a normalized, area-under-the-curve (AuC) metric, ranging from 0.0 (maximal discounting) to 1.0 (no discounting).[4]

3 x 2 x 2 (*Group* x *Task* x *Amount*) Mixed ANOVA

- Main effect of *Group* was not significant, $F(2,45) = 1.97$, $p = .151$
- **Significant *Group* x *Task* interaction**
  $F(2,45) = 6.32$, $p = .004$, $\eta^2_p = .219$
- **Significant three-way *Group* x *Task* x *Amount* interaction**,
  $F(2,45) = 4.10$, $p = .023$, $\eta^2_p = .154$.
- **Significant *Task* x *Amount* interaction**
  $F(1,45) = 5.73$, $p = .021$, $\eta^2_p = .113$.

Planned Comparisons

1) **MTL vs. Controls for DD:** No significant main effect of *Group*, $F(1,38) = .011$, $p = .917$, or *Amount*, $F(1,38) = 4.08$, $p = .051$; no significant *Amount* x *Group* interaction, $F(1,38) = 1.73$, $p = .196$.

2) **vmPFC vs. Controls for DD:** No significant main effect of *Group*, $F(1,36) = 1.74$, $p = .196$, or *Amount*, $F(1,36) = 1.43$, $p = .239$; **significant *Group* x *Amount* interaction,** $F(1,36) = 6.50$, $p = .015$, $\eta^2_p = .038$.

3) **MTL vs. Controls for PD:** **Significant main effect of *Group***, $F(1,38) = 10.13$, $p = .003$, $\eta^2_p = .211$, and ***Amount***, $F(1,38) = 29.60$, $p < .001$, $\eta^2_p = .438$; interaction of *Group* x *Amount* was not significant, $F(1,38) = 1.70$, $p = .200$

4) **vmPFC vs. Controls for PD:** **Significant main effect of *Group***, $F(1,36) = 23.10$, $p < .001$, $\eta^2_p = .391$; no main effect of *Amount*, $F(1,36) = 1.28$, $p = .265$. **Significant *Group* x *Amount* interaction**, $F(1, 36) = 4.27$, $p = .046$, $\eta^2_p = .106$. Group differences found for both smaller, $F(1,36) = 13.54$, and larger reward amounts, $F(1, 36) = 30.40$, $ps < .001$.

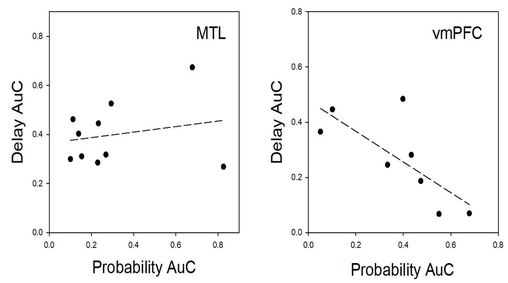


Figure 5. Patients' mean AuCs for delay discounting plotted as a function of their mean AuCs for probability discounting.

Correlation for DD & PD

Correlation were not significant for Controls, $r = .163$, $p = .389$, or MTLs, $r = .214$, $p = .553$.

In contrast, vmPFCs had a **significant, negative correlation**, $r = -.750$, $p = .032$.

Discussion

(1) vmPFC patients discounted delayed rewards more steeply but discounted probabilistic rewards more shallowly than controls and MTL patients. This significant negative correlation between DD and PD may suggest increased impulsiveness that is found in vmPFC patients only.

(2) Contrary to traditional views, reward immediacy (DD) and reward likelihood (PD) may describe two distinct functions that require differential weighing of reward amount. Future work should explore the vmPFC's role in integrating multiple opposing systems of reward discounting.

References [1]Green & Myerson (2013) *J Exp Anal Behav*; [2]Fellows & Farah (2007) *Cereb Cortex*; [3]Sellitto et al. (2010) *J Neuro*; Myerson et al. (2001) *J Exp Anal Behav*;