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Experimental Tests of the Somatic Marker Hypothesis

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Abstract

Damasio's (1994) Somatic Marker hypothesis posits that emotion-generated mental markers influence our decisions and, in particular, tend to curb inherent tendencies to seek risk, to be impatient and to be callous in social situations. Ventromedial (VM) prefrontal cortex damage interferes with this marking process, resulting in risk seeking behavior, impatience and socially inappropriate behavior. In the present study, we present 27 normal controls and 17 patients with prefrontal cortex lesions with batteries of questions designed to probe their attitudes toward risk, intertemporal preferences and behavior in social contexts. The results demonstrate that VM patients are no more risk seeking, impatient, or prone to behavior in socially inappropriate manners than normal subjects. Indeed, we find no significant differences of any sort between the two groups of subjects on any the dimensions investigated. We discuss why VM cortex damage in humans appears to influence decisions in certain circumstances but not in others.

I. <u>Introduction</u>

In his book, Descarte's Error (1994), Antonio Damasio describes the behavior of people who have suffered damage to a specific portion of the brain -- the ventromedial pre-frontal cortex. Individuals with damage to the ventromedial pre-frontal cortex are often described as being "impulsive," "impatient," "indecisive," "emotionally flat," and "socially incompetent." Damasio (1994) explains these behaviors in the context of what he terms the Somatic Marker hypothesis. Briefly stated, this hypothesis assumes that decisions are arrived at through the interplay of two processes. One is deliberative and goal oriented. This process is assumed to favor alternatives offering larger rewards and/or more immediate gratification, biasing individuals toward risk seeking behavior and impatience. In normals, this deliberative process is supplemented and, in some cases, supplanted by a very fast, experience based, largely subconscious, and affect-driven decision process. In this process, the available options are scanned. Each option's component consequences elicit visceral reactions based upon past experience which, in turn, mark or bias the individual toward or against that option. Positively marked items become candidates for choice or conscious deliberation whereas negatively marked options are dropped from further consideration. This affective process operates to override our inherent tendency to select risk seeking options and those offering immediate gratification when these options also entail substantial downside or future penalities.

The most compelling empirical evidence for this hypothesis comes from a gambling experiment in which ventromedial (VM) and normal control (NC) subjects were initially endowed with $2000 in play money and asked to repeatly make choices between four decks of cards. (Bechara et al 1994, 1997). All cards in all decks paid an amount of money but some cards in all decks required that subjects pay money back. Two of the decks were "risky" in the sense that, while they offered large certain payoffs (e.g., $1000), they also involved very large occasional losses such that the expected value of drawing from these decks was negative. The "safe" decks, in contrast, offered modest gains and losses and had positive expected values. Subjects were instructed to play the game so as to lose as little as possible and win as much as possible. Subjects' autonomic nervous system states were measured by skin conductance responses (SCR) collected throughout the course of the game (presumably a surrogate for the somatic marker).

NC subjects playing this game initially selected randomly from the different decks, gravitated toward the riskier ones until they encountered losses and then began systematically favoring the safe decks. NC subjects exhibited SCR to incurred gains and losses but, as experience accumulated, also began to exhibit SCR prior to selections from the risky but not the safe deck – "anticipatory" reactions consistent with somatic marking of the risky decks.

VM subjects, like their NC counterparts, initially sampled from the decks randomly and then began to favor the risky ones. In contrast to NC, however, they persisted in choosing from these decks even as experience with losses accumulated. Moreover, while they exhibited SCR to experienced gains and losses, they never developed anticipatory SCR to the risky decks – the risky decks were never assigned the somatic markers that never that would discourage VM subjects from choosing them.

These and related experimental findings seem to confirm Damasio's conjecture that damage to the ventromedial prefrontal cortex disrupts the somatic marking process.

One consequence is indecision. Individuals with prefrontal cortex damage have only the deliberative, computationally intensive process to rely upon to make decisions – a process that breaks down in complex situations involving many options and large numbers of potential consequences. A second consequence is risk seeking. In circumstances involving choice between high reward/high risk options and lower reward/lower risk ones, Damasio (1994, pp. 173) conjectures that normals and individuals with prefrontal cortex damage alike, are initially attracted to the former by virtue of their higher payoffs. In normals, this tendency is modified by experience with those options - high reward/high risk options are subconsciously assigned negative somatic markers as people experience the large losses they occasionally entail. In individuals with prefrontal cortex damage, these markers are never assigned.

In decisions involving an intertemporal dimension, Damasio proposes that prefrontal cortex damage produces impatience. Here, because the potential benefits of deferred consequences are not viscerally anticipated, there is nothing to counter our inherent tendency to "go for the now rather than bank on the future." (Damasio, 1994, pp. 217)

Finally, Damasio suggests that damage to the prefrontal cortex produces socially inappropriate behavior and failure to behave altruistically, to the extent that immediate benefits from deviating from norms or behaving self-servingly are not properly balanced by (unmarked) future consequences associated with guilt and/or ostracism. (Damasio, 1994, pp. 176)

To test these claims, we administered a set of experiments designed to investigate and characterize peoples' attitudes toward risk, willingness to delay gratification, and behavior in social situations to forty four subjects.[1] Twenty-seven of these subjects were normal controls, five of whom were women.[2] An additional seventeen subjects had ventromedial frontal lobe lesions where the classification was based on an examination of subjects' lesion templates (Damasio and Damasio, 1989). All VM subject were male.[3] Characteristics of the subjects are shown in Table 1.

Table 1

		Normal Controls NC	Ventromedial VM
Age	Mean	55.7	54.4
	SE	1.87	1.53
	Min	42	50
	Max	77	69
Education	Mean	15	14
	SE	0.39	0.65
	Min	12	11
	Max	18	22
N subjects		27	17
N women		5	0
N right-handed		23	15

1 Eight subjects with non-ventromedial frontal lobe lesions also completed the questionnaires. Since there are no clear predictions regarding how the behavior of these subjects might compare to that of normal controls nor ventromedial subjects, they are excluded from the analysis. Their inclusion has no impact on the basic results.

2 Only one result, noted in the text, changes substantively if women are excluded from the analyses.

3 All results reported in the ensuing sections combine male and female subjects.

All subjects were administered all experiments. The first experiment reported here examined subjects' attitudes toward risk, the next three examined subjects' intertemporal preferences and the final experiment examined subjects' play and their expectations about opponents' play in simple strategic games.[4] Our results, reported in the ensuing sections, do not support predictions of the Somatic Marker hypothesis – subjects with ventromedial damage are not significantly more risk seeking nor impatient that normal controls nor are they less likely to adhere to social norms. Indeed, we find no significant differences of any sort between the two groups of subjects on any the dimensions investigated. We discuss possible explanations for these and related negative findings regarding the Somatic Marker hypothesis in the conclusions to the paper.

II. Risk Preference - Choice Among Risky Lotteries

The Somatic Marker hypothesis implies that VM individuals are more risk seeking than normals. To test this hypothesis and, more generally, characterize aspects of VM and NCs behavior under uncertainty, all subjects were asked Questions 1 through 11 shown below.

> This questionnaire consists of 11 problems. In each problem, you are asked to choose between Option A and Option B. Each of these options offers some chance of winning an amount of money but also some chance of winning nothing or losing money.
>
> Here is an example of the type of question you will be asked.
>
> Option A Win $8 (20% chance), Lose $9 (80% chance)
> Option B Win $5 (40% chance), Lose $1 (60% chance)

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[4] Two other experiments were conducted using methods commonly employed by decision analysts to elicit subjects' value and utility functions. Value functions reflect how subjects' attitudes toward money vary with the amount of money. Utility functions reflect attitudes toward risk. No systematic differences between subject groups were found for either of these experiments. There were, however, a large number of unusable and nonsensical responses to these questions across groups suggesting that many subjects, irrespective of group, did not understand the tasks. Given this, we chose not to discuss these results here. Details and analysis of these experiments are available from the authors.

For each of the following, place a check mark next to the lottery you would prefer to play.

Q 1
Option A win $2000 (45% chance), win $0 (55% chance)______
Option B win $1000 (90% chance), win $0 (10% chance)______

Q 2
Option A win $2000 (1 % chance), win $0 (99% chance)______
Option B win $1000 (2 % chance), win $0 (98 % chance)______

Q 3
Option A lose $6000 (40% chance), lose $0 (60% chance)______
Option B lose $3000 (80% chance), lose $0 (20% chance)______

Q 4
Option A lose $6000 (4% chance), win $0 (96% chance)______
Option B lose $3000 (8% chance), win $0 (92% chance)______

Q 5
Option A win $750 (50% chance), lose $750 (50 % chance)______
Option B win $0 (50% chance), lose $0 (50% chance)______

Q 6
Option A win $1400 (50% chance), win $1600 (50% chance)______
Option B win $1100 (50% chance), win $1900 (50% chance)______

Q 7
Option A win $2000 (1% chance), win $0 (99% chance)______
Option B win $1000 (2% chance), win $0 (98 % chance)______

Q 8
Option A win $344 (98% chance), win $344 (2% chance)______
Option B win $350 (98% chance), win $150 (2% chance)______

Q 9
Option A lose $424 (96% chance), lose $424 (4% chance)______
Option B lose $440 (96% chance), lose $80 (4% chance)______

Q 10
A win $5 (20%), win $5 (20%), win $0 (40%), win $13 (20%) ______
B win $0 (20%), win $12 (20%), win $5 (20%), win $0 (20%) ______

Q 11
A win $0 (20%), win $13 (20%), win $5 (40%), win $0 (20%) ______
B win $5 (20%), win $5 (20%), win $0 (40%), win $12 (20%) ______

Each of the first 9 questions involves a choice between lotteries with identical expected values but different variances. Risk averse individuals will prefer the lower variance gambles, risk neutral individuals will be indifferent between the higher and lower variance options, and risk seekers will prefer the lottery with higher variance.

The percentages of NC and VM subjects choosing the riskier option on questions 1 through 9 are shown in Table 2. The NC group is risk seeking in four of nine cases while the VM group is risk seeking for five of the nine questions. Differences in the percentage of subjects choosing the riskier option across groups tend to be small.[5]

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Table 2

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	n=
RS NC	**4%**	50%	**69%**	**48%***	65%	**48%***	**65%**	**15%**	**96%**	26 (*=25)
RS VM	**25%**	**56%**	**56%**	56%	69%	50%	31%	**13%**	**69%**	17
Expected	RA	RS	RS	RA	RA	RA	RS	RA	RS	

To formally test whether VM subjects are more risk seeking than normals, each individual in each group was assigned a score according to the number of times he or she selected the risk seeking option across the 9 questions.[6] If VM subjects are more risk seeking we expect the median score for VM subjects to exceed that of NC subjects. However, as indicated in Table 3, the median score for NC subjects and the proportion of

5 The small number of VM choosing the risky option in Q7 is the exception to this statement and peculiar given that this question is identical Q20 for which all groups were almost equally split in favor of the risky and safer alternatives.

6 There are 24 NC subjects in this analysis as two NC subjects failed to answer some questions and one did not answer any.

their scores lying above the overall median both exceed those for VM subjects. As such, it is NC subjects that appear more risk seeking although the difference between group medians is not statistically significant (Fisher exact p=.174, 1-tailed test).

Table 3

Subject Type	N	Individual Medians	> Overall Median	≤ Overall Median
NC	24	5	7	17
VM	17	4	2	15

In addition to asking whether VM subjects are more risk seeking than NCs as per the Somatic Marker Hypothesis (a one-tailed test), we also considered whether VM respondents, as a group, differed from NC subjects in other ways (two-tailed tests). Research examining how people choose between lotteries of the type presented to subjects here has identified a number of robust features of individual decision making. Numbers in bold in Table 3 indicate questions for which the majority of responses of NC and VM subjects, respectively, correspond to what would be expected based on responses to questions of this type found in the decision making literature. NC subjects agree with what would be expected based on the literature in 7 of 9 cases while VM subjects agree in 5 of 9 cases.

One robust finding from research on decision making is that people tend to reject symmetric bets (e.g., a 50:50 chance of winning or losing some amount of money)[7] -- a tendency interpreted as indicating the subjects' utility functions are steeper for losses than

[7] Friedman and Savage (1948) emphasized the general tendency for people to reject symmetric bets and to prefer / dislike positively / negatively skewed lotteries.

gains. Q5 offers subjects such a choice. The numbers of subjects accepting and rejecting this bet are shown below. [8]

Table 4a

Question #	Risk Seeking Option (RS)	Risk Averse Option (RA)
Q5	($750,.5;-$750,.5)	$0

	Accept	Reject
NC	17	9
VM	12	5

As indicated, a majority of subjects here choose to play the bet rather than abstain, contrary to the finding reported in the literature. The numbers doing so do not, however, differ between groups (Fisher 2-tailed exact p=1.000).[9]

A second robust finding from research on lottery choice is that for questions like Q1 and Q6 involving gains at moderate probabilities, people tend to be risk averse – choosing the safe option in both questions.[10] The numbers of subjects in each group exhibiting each of the possible preference patterns for these two questions are shown below.

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[8] The notation used to describe lotteries, for example, ($750, .5 ; -$750, .5) implies that the outcome $750 occurs with probability .5 and the outcome -$750 with probability of .5.

[9] All Fisher two-tailed probabilities are $p(O \geq E \mid O \leq E)$.

[10] See Markowitz (1952) and Kahneman and Tversky (1979).

Table 4b

Question #	Risk Seeking Option (RS)	Risk Averse Option (RA)
Q1	($2000,.45;$0,.55)	($1000,.90; $0,.10)
Q6	($1100,.50; $1900,.50)	($1400,.50;$1600,.50)

	RARA	RARS	RSRA	RSRS
NC	13	11	0	1
VM	7	6	2	2

A majority of NC subjects choose the risk averse alternative on both these questions, while slightly less than 50% of VM subjects do so. The distributions of preference patterns do not differ significantly between groups ($\chi^2_{df=3}$ =4.2337, 2-tailed p=0.2373).

For losses at moderate probabilities, as in Question 3, people tend to be risk seeking. As indicated below, a majority of subjects in each group behave in this manner.

Table 4c

Question #	Risk Seeking Option	Risk Averse Option
Q3	(-$6000,.40;$0,.60)	(-$3000,.80; $0,.20)

	RA	RS
NC	8	18
VM	7	10

Once again, the hypothesis that the distributions of risk preferences for losses is the same across groups cannot be rejected (Fisher 2-tailed exact p=.5279).

Departures from the common tendency to be risk averse for gains and risk seeking for losses arise, at least in part, because people appear to overweight low probabilities.[11] In the context of Q2 (and Q7 which is identical) involving gains, this tendency favors the choice of the riskier option whereas in Q4, involving losses, it favors the safer. Preference patterns for Questions 2 and 4 (7 and 4) are shown below by group.

Table 4d

Question #	Risk Seeking Option	Risk Averse Option
Q2 (7)	($2000,.01;$0,.98)	($1000,.02; $0,.98)
Q4	(-$6000,.04;$0,.96)	(-$3000,.08; $0,.92)

	RARA	RARS	RSRA	RSRS
NC	6 (2)	6 (6)	7 (11)	6 (6)
VM	3 (4)	5 (7)	4 (3)	5 (3)

The RSRA pattern expected is the modal pattern for NC subjects but not for VM. However, the hypothesis that the distributions of preference patterns are the same for the two groups cannot be rejected for either choices between Q2 and Q4 nor between Q7 and Q4 ($\chi^2_{df=3}$ =0.494 (6.297), 2-tailed p=0.9201 (0.098)).

A final robust characteristic of choices under uncertainty identified though lottery choices concerns decisions between very skewed lotteries and their expected values. For choices in which the lottery is negatively skewed (i.e., has a distribution with a long left tail) people tend to dislike gambling. This preference explains why people find the purchase of insurance attractive. Conversely, people tend to like lotteries with that are

[11] Machina (1982) contains a summary of evidence suggesting overweighting of low probabilities in both choice data and from efforts to empirically fit expected utility models. Overweighting of low probabilities is also a central feature of Kahneman and Tversky's (1979) Prospect Theory.

positively skewed (i.e., have long right tails.) This preference explains the attractiveness of things like state lotteries. Questions 8 and 9 offer subjects choices between skewed lotteries and expected values. As indicated below, almost 2/3rds of VM and greater than 2/3rds of NC subjects exhibit the expected choice pattern, being risk averse in Q8 and risk seeking in Q9.

Table 4e

Question #	Risk Seeking Option	Risk Averse Option
Q8	(\$350,.98; \$150,.02)	(\$344,.98;\$344,.02)
Q9	(-\$440,.96; -\$80,.04)	(-\$424,.96;-\$424,.04)

	RARA	RARS	RSRA	RSRS
NC	1	21	0	4
VM	4	11	1	1

The differences in response frequencies are not significant across groups ($\chi^2_{df=3}$ =6.1089, 2-tailed p=0.1064).

In contrast to all other results reported in this paper, this finding does not continue to hold if the 5 NC women are excluded from the analysis. In this case, 20 of the remaining 21 NC subjects exhibit the pattern RARS with the remaining subject choosing RSRS. This response pattern differs significantly from the pattern exhibited by VM subjects at (Fisher exact 2-tailed test p=.0153). For Q8 involving gains, very high proportions of NC male (95%) and VM male (88%) subjects exhibit risk aversion. For the loss question, Q9, 100% of NC males choose the risky option whereas only 71% of VM subjects do. So the difference in response patterns between groups results because VM subjects are too risk averse for losses.

The questions discussed to this point provide insight into what types of lotteries subjects prefer. Question pair 10 and 11 and pair 2 and 5 examine different issues. Specifically, Q10 and Q11 enable us to examine whether the way normal and brain damaged subjects evaluate lotteries is the same. In standard models of decision making under uncertainty (e.g., expected utility, Prospect theory), people given a choice between two lotteries, assign an index value to the first reflecting its desirability, an index value to the second, and then choosing the one with the higher index value. Index values are independent of the other alternative choices available. Tversky (1969), Rubinstein (1988), and Leland (1994, 1998) have suggested that people instead base their decisions on simple comparisons regarding the similarity of prizes and probabilities across lotteries. Such a comparative procedure can lead people to make choices definable as decision errors. To illustrate, note that in Q10 and Q11, the A option corresponds to the lottery ($5, .4 ; $0,.4 ; $13,.2) while the B option corresponds to ($5, .4 ; $0,.4 ; $12,.2). As such, A should be preferred in both cases since it offers a better outcome, $13 versus $12, 20% of the time and the same outcomes at identical probabilities the rest of the time. People almost inevitably choose A in Q10. However, in Q11, a majority often choose option B – presumably because in the comparison of outcomes $0, .2 and $12, .2, the latter prize is noticeably better than the former, favoring selection of option B. Combined, we expect the choice pattern AB which is, as indicated below, the modal pattern exhibited by both NC and VM groups.

Table 4f

Question #	Option A	Option B
Q10	($5,.20;$5,.20;$0,.40;$13,.20)	($0,.20;$13,.20;$5,.40;$0,.20)
Q11	($0,.20;$12,..20;$5,.40;$0,.20)	($5,.20;$5,..20;$0,.40;$12,.20)

	AA	AB	BA	BB
NC	8	13	3	2
VM	4	8	3	2

Distributions of all four possible response patterns do not differ significantly between groups ($\chi^2_{df=3}$ =0.6694, 2-tailed p=0.8804).

VM subjects are often described as both indecisive and impulsive suggesting they are less consistent in the choices they make than are NCs. Questions 2 and 7 presented subjects with the identical decision. The numbers of NC and VM subjects choosing consistently and inconsistently across these two questions are shown below.

Table 4g

Question #	Risk Seeking Option	Risk Averse Option
Q2	($2000,.01;$0,.98)	($1000,.02; $0,.98)
Q7	($2000,.01;$0,.98)	($1000,.02; $0,.98)

	Consistent	Inconsistent
NC	18	8
VM	8	9

While consistency in responses is, in general, quite low, and notably so for VM subjects, VM subjects are not significantly less consistent (Fisher 1-tailed exact p=.1284).

In summary, in our omnibus test of whether VM subjects are more risk seeking than NC subjects, we cannot reject the hypothesis that risk preference is independent of group. Moreover, tests examining whether VM subjects differ from NC subjects in other respects, with one exception, fail to find any significant differences. In the one case where a significant difference in responses was found – between NC males and VM subjects all of whom were male, the result is driven by the fact that VM subjects appear less risk seeking for losses – not more as implied by the Somatic Marker hypothesis.

IIIa. Time Preference – Individual Discount Rates

The Somatic Marker hypothesis implies that VM individuals are more impatient than normals. We used two methods to test this hypothesis. In the first, subjects were told they could receive some amount today ($100, $500, $1000, $2000) and asked how much they would have to receive at a future date (1 week, 6 months, 1 year, 6 years) to make them indifferent between receiving money now versus later (as in Q12 through Q27 shown below). A person's answers to questions like these can be used to compute that person's annual discount rate, reflecting the premium or penalty he or she requires to defer consumption of a given amount of money one year. For economic reasons, this rate should be positive – people should be impatient. If the person is rational, it should also be constant – not varying with either the amount to be received now or the length of time the alternative payment will be delayed.[12] In experiments, however, people's discount rates have been shown to decrease with both amount and delay.

[12] If this is not the case, the individual will suffer from what is referred to as "dynamic inconsistency" – making plans and commitments today which, in the future at a different discount rate, he or she will always want to alter.

Imagine that you have won a promotional contest conducted by your bank. They will either pay you a specific amount of money today or a larger sum at a future date. For each question below state the amount of money to be received at the specified date in the future that would make waiting just as attractive as receiving the smaller amount today. Answer each question as if it is the only one facing you. Also, assume that there is no question about receiving the money in the future (i.e., even if you change banks or the bank goes out of business, your payment is ensured).

write amount here

Q12)You receive $100 today or _________ 1 week from now.

Q13) You receive $100 today or _________ 6 months from now.

Q14) You receive $100 today or _________ 1 year from now.

Q15) You receive $100 today or _________ 6 years from now.

Q16) You receive $500 today or _________ 1 week from now.

Q17) You receive $500 today or _________ 6 months from now.

Q18) You receive $500 today or _________ 1 year from now.

Q19) You receive $500 today or _________ 6 years from now.

Q20)You receive $1000 today or _________ 1 week from now.

Q21) You receive $1000 today or _________ 6 months from now.

Q22) You receive $1000 today or _________ 1 year from now.

Q23) You receive $1000 today or _________ 6 years from now.

Q24)You receive $2000 today or _________ 1 week from now.

Q25) You receive $2000 today or _________ 6 months from now.

Q26) You receive $2000 today or _________ 1 year from now.

Q27) You receive $2000 today or _________ 6 years from now.

They also tend to be extremely high, particularly for small amounts and short delays, relative to rates at which people can borrow and lend in markets.

Twenty-four NC and 15 VM subjects provided complete, usable answers to all 16 discount rate questions.[13] Table 5 summarizes the median and geometric mean responses for each subject group by amount and delay.

Three things are of particular note in this table. First, note that, consistent with the Somatic Marker hypothesis, comparison of median discount rates suggests VM subjects are more impatient – for every amount and every delay their median discount rate is larger than the corresponding rate for NC subjects. A comparison of the geometric mean rates, on the other hand, suggests that NC subjects are more impatient at 1 week and 6 month delays and more patient for a 1 year delay. Geometric means for the two groups are comparable for 6 year delays.

Second, discount rates for both groups are very high and astronomical for delays of 1 week. They are not, however, necessarily out of line in comparison to studies of this type.[14]

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[13] One NC failed to answer any of these questions, two others failed to provide an answer to one of the questions, and two VM's provided some answers implying negative discount rates.

[14] For example, Chapman and Elstein (1995) asked 70 subjects how much they would require to delay receiving $200 for 6 months and 1 year. Geometric mean rates implied by subjects' responses were approximately 400% and 200% -- not very different from rates found here, although Chapman and Elstein note that the rates they observed were quite high. In one of the few studies to examine rates for delays shorter than a year, Chapman (1998) reports an average geometric mean discount rate of 2189% derived from responses to questions involving 10 amounts varying from $5 to $160 and a delay of 3 months.

Table 5

Delay =	1 Week	6 Months	1 Year	6 Years
Discount rates for:				
$100 today				
NC Median	14104%	125%	100%	43%
VM Median	10947544%	800%	400%	62%
NC Geomean*	*****	1051%	324%	45%
VM Geomean	5576662429255%	526%	221%	48%
$500 today				
NC Median	5371%	50%	55%	30%
VM Median	14104%	300%	300%	47%
NC Geomean	*****	463%	174%	35%
VM Geomean	7332026111%	247%	237%	39%
$1000 today				
NC Median	14104%	125%	100%	33%
VM Median	14104%	384%	200%	35%
NC Geomean	*****	654%	162%	39%
VM Geomean	33000275177967600%	447%	181%	33%
$2000 today				
NC Median	14104%	107%	87%	31%
VM Median	546745%	300%	150%	35%
NC Geomean	*****	415%	169%	34%
VM Geomean	5505414364979%	232%	174%	32%

* Geometric means are computed only for subjects with positive discount rates.
***** indicates astronomically large discount rates

Finally, median and geometric rates decline systematically for both groups of subjects as delay increases, consistent with findings reported elsewhere. Median and geometric mean rates for NC and VM subjects do not, however, clearly decline with amount as has been found in other studies.

To further examine whether VM discount rates exceed those of NC subjects as well as examine whether there are other obvious differences in the VM responses, a repeated measures ANOVA was conducted with ln(1 + discount rate) as the dependent variable, subject group as a between-subject factor, and delay, amount, and all interactions as within-subjects factors. The between-subject ANOVA results do not support the hypothesis that VM subjects have systematically higher discount rates than normals ($F(1,37)=1.015$, $p=.32$).

Within-subject results of the ANOVA do confirm some of the implications drawn from Table 5. Specifically, there is a significant main effect for delay (Wilks' Lambda = .518, $F(3,35)=10.845$, $p=.000$). The main effect for amount, however, falls just shy of significance (Wilks' Lambda = .807, $F(3,35)=2.795$, $p=.055$.) and interactions are insignificant.

In most studies of this type, minimum delays are in the 6 month to 1 year range. To increase comparability with these studies, a second analysis was conducted with responses to the 1 week delay questions excluded. For this subset of the data, as in other studies (e.g., Chapman and Elstein (1995), Chapman (1996), Chapman (1998)), there were significant main effects for delay (Wilks' Lambda =.568, $F(2,39)=14.833$, $p=.000$) and for amount (Wilks' Lambda = .737, $F(3,38) = 4.528$, $p=.008$). The interaction between delay and amount falls just shy of significance (Wilks' Lambda = .718, $f(6,35)$

= 2.294, p=.057). As before, there is no significant between-subjects effect (F(2,40) = .005, p=.945.) In summary, the data do not support the hypothesis that VM subjects are systematically more impatient than NC subjects. Instead their discount rates appear comparable and their response patterns exhibit the same characteristics found among normals here and in the literature.

IIIb. Time Preference – Anticipation and Savoring Behavior

In the theory of intertemporal choice, positive time preference implies that people should want to get good things sooner and defer bad ones until later. Loewenstein (1987) and Loewenstein and Prelec (1993) argue that this may not be the case, particularly for non-monetary goods. Instead, people may prefer to delay receipt of good things and choose to get bad things over with. Loewenstein attributes such behavior to the anticipatory utility associated with the thought of receiving goods in the future and the anticipatory disutility associated with entertaining unpleasant events to occur in the future. To the extent that damage to the ventromedial prefrontal cortex disrupts these anticipatory processes, as suggested by Bechara et al's (1994, 1997) findings[15], we would, somewhat paradoxically, expect individuals with frontal lobe lesions to behave more in line with rational theory in choices among non-monetary options – they should exhibit positive time preference. To examine this possibility, NC and VM subjects were presented with the following question:

[15] Recall that Bechara et al (1994, 1997) found that while NC's developed anticipatory skin conductivity responses when they entertained drawing from high risk decks, VM subjects didn't developed these anticipatory responses.

Q28) A number of companies now offer “Dining Out” discount cards that give you between 10% and 25% off your bill each time you go out to eat at one of the participating restaurants. As a promotion for this service, one of these companies sends you a coupon for a free meal at one of their participating restaurants -- a very nice French restaurant. Due to time constraints, you can only go to the restaurant this weekend or the next. Place a check next to the option you like better.

	This Weekend	**Next Weekend**	
Option A:	Fancy French dinner	Eat at home	_____
Option B:	Eat at home	Fancy French dinner	_____

Assuming dinner in a fancy French restaurant is preferred to eating at home, impatience (i.e., a positive discount rate) requires the choice of A—a fancy French dinner this weekend should be preferred to one the following weekend and more so by VM subjects. As indicated in Table 6, however, 17 of 25[16] (68%) of NC subjects choose A versus 11 of 17 (65%) of VM who do so – it is NC subjects that appear more impatient although not significantly so (Fisher 2-tailed exact p=1). [17]

Table 6

	A > B	B < A
NC	17	8
VM	11	6

In addition to finding that people like to defer (speed-up) consumption of goods (bads), Loewenstein and Prelec (1993) report results suggesting that people also like to spread out the experience of good events over time. Imagine, for example, that over the

[16] Two NC failed to answer this question.

[17] In oewenstein and Prelec (1993), a similar proportion of subjects, 57%, preferred an option offering dinner in a French restaurant in 2 months and a Greek restaurant in 1 month to an option offering the dinner at the French restaurant in 1 month and the Greek restaurant in 2 months.

next three weekends you must do a very boring task on one weekend, engage in a nice activity on another, and engage in a very pleasurable one on a third. If you were truly impatient, you would choose to do the pleasurable activity this weekend, the nice one the next, and defer the unpleasant one until last. Conversely, if you were motivated purely by anticipatory utility ala the French restaurant example, you would do the boring task first, then the nice and save the pleasurable one for last. Loewenstein and Prelec (1993) find instead, that people tend to choose to do the nice task first, then the boring, and then the pleasurable. This tendency to spread out good events temporally and save the best for last suggests we not only get utility from anticipating good things to occur in the future but also utility from savoring them after they are experienced. To the extent that visceral recollections of past events extinguish rapidly in individuals with ventromedial prefrontal cortex lesions, they may be uninterested in arranging events so as to promote savoring. To examine this possibility and further explore whether VM subjects are more impatient as a consequence of inability to anticipate, members of our subject groups were presented with the following task.

Q29-32: You are contemplating the next five weekends. Your situation is as follows:

- One of the five weekends you will be able to do something “Pleasurable” -- an activity you really enjoy doing on weekends.

- Two of the five weekends you will be able to do something “Nice” -- an activity that for you is a moderately pleasurable way to spend the weekend.

- Two of the five weekends you will have to do something “Boring” -- an activity that is not fun to do.

Below are four different plans for spending your next five weekends. Please rank these from the plan you would most like to follow to the plan you would least like to follow. Assign the best plan the number "1", the second best plan the number "2", the third a "3" and the least desirable plan the number "4."

	Week 1	Week 2	Week 3	Week 4	Week 5	
A	Nice	Boring	Nice	Boring	Pleasurable	_____
B	Pleasurable	Nice	Nice	Boring	Boring	_____
C	Boring	Boring	Nice	Nice	Pleasurable	_____
D	Pleasurable	Boring	Nice	Boring	Nice	_____

Pure impatience would rank these options as B first, then D, then A and then C. Individuals solely interested in maximizing the opportunity to anticipate good outcomes would rank them in exactly the opposite order -- C preferred to A preferred to D preferred to B.

Preference patterns exhibited by 24 NC and 14 VM subjects are shown in Table 7 where patterns are organized according to whether option B, corresponding to pure impatience, is ranked 4th, 3rd, 2nd, or 1st.[18] Overall, the frequencies with which the

[18] Subjects excluded from the analysis either failed to respond or only ranked one option as best.

different possible response patterns are exhibited by members of the two groups are quite similar. A majority of both groups choose rankings in which B is least preferred. Consistent with the hypothesis that VM subjects are more impatient, the ordering BDAC, corresponding to pure impatience, is favored by a larger percentage of VM subjects (14% vs. 4%). On the other hand, the percentage of VM favoring the ranking corresponding to an interest only in anticipation, CADB, is also slightly larger (14% vs. 13%).

Table 7

Ranking	NC		VM	
ACDB	4	17%	2	14%
ADCB	5	21%	2	14%
CADB	3	13%	2	14%
CDAB	1	4%	0	0%
DACB	4	17%	2	14%
	17	71%	8	57%
ADBC	3	13%	1	7%
DABC	0	0%	1	7%
	3	13%	2	14%
ABCD	0	0%	0	0%
ABDC	1	4%	1	7%
CBAD	0	0%	1	7%
CBDA	1	4%	0	0%
	2	8%	2	14%
BADC	1	4%	0	0%
BDAC	1	4%	2	14%
	2	8%	2	14%

To more formally test the hypothesis that VM subjects are more impatient we tally the number of subjects in each group who rank B, the pure impatient option, over C, the pure patient option, and rank D, the savoring but impatient option, over A, the savoring but patient option. We define these respondents as "Impatient." We then count the number of subjects in each group who do the opposite (i.e. rank C over B and A over D) and define these as the "Patient" subjects. The remaining subjects are categorized as "Other." Counts for VM and NC subjects are shown in Table 8.

Table 8
Impatient vs. Patient

	Impatient	Patient	Other
NC	1 (4%)	12 (50%)	11 (46%)
VM	3 (21%)	7 (50%)	4 (29%)

Though a larger percentage of VM subjects are classified as impatient (21% vs. 4%), the hypothesis that the distributions of responses are independent of group cannot be rejected ($X^2_{2df} = 3.17$, p=.2049).

To examine the hypothesis that VM subjects are unable to savor consumption ex-post, we classified NC and VM respondents as "Savorers" if they ranked option D, which reflects impatience but spreads consumption, over B, the impatient option with no spreading, and if they ranked A, the patient option which spreads consumption, over C, the patient option with no spreading. Subjects rankings B over D and C over A were classified as "Non-savorers," with the remaining subjects classified as "Other." Numbers of subjects in each category by subject type are shown in the bottom of Table 9.

Table 9

Savor vs. Not

	Savorers	Non-savorers	Other
NC	16 (67%)	1 (4%)	7 (29%)
VM	7 (50%)	1 (7%)	6 (43%)

Once again, while a somewhat larger percentage of VM subjects are categorized as non-savorers, we cannot reject the hypothesis that preferences for sequences that afford opportunities to savor are unrelated to subject type (X^2_{2df} = 1.039, p=.5948).

IV. Social Interactions – Play and Expectations in Games

VM patients are prone to behave in socially inappropriate ways like swearing in mixed company. Damasio (1994) suggests two ways disruption of signals from the prefrontal cortex might explain this. The first follows from VM individuals being impulsive and impatience -- the costs associated with violating social norms, either those associated with personal guilt or those resulting from retribution by others, are simply not considered.

A second explanation concerns VM individuals' inability to predict or anticipate the reactions of others in social circumstances. Specifically, Damasio suggests that "The somatic marker hypothesis is thus compatible with the notion that effective personal and social behavior requires individuals to form adequate "theories" of their own minds and of the minds of others. On the basis of those theories we can predict what theories others are forming about our own mind" (Damasio, 1994, pp. 174).

Two situations drawn from game theory were employed to test these hypotheses. In the first situation, referred to as a "dictator game", the subject is asked to divide a fixed amount of money between him or herself and an anonymous stranger. Anonymity assures there is no possibility of retribution. Rationality, as defined in game theory, prescribes that individuals in dictator games should make the most extreme split possible, keeping all the money. In actual experiments, however, equal splits tend to be the modal response with exceptions tending to favor the dictator. The structure of offers appears to result from people adhering to a norm of fairness or concern over what other people and, in particular, the experimenter, might think of them, shaded by self-interest. (Thaler (1986), Forsythe et al (1991), Eckel et al (1996)).

NC and VM subjects were presented with the dictator game scenario (shown below) and asked how much they would keep (Q34) and how much they thought the person with whom they were hypothetically matched would offer if he or she got to decide the division (Q36).[19]

Situation 1

Imagine a situation in which $10 is to be divided between you and another person. One of you will be asked to divide the money. Any division from $10 for you and $0 for the other person to $0 for you and $10 for the other person is allowed. You and this other person don't know each other and will never meet.

Suppose you get to decide how to divide the $10 between yourself and this other person. How much of the $10 would you keep and how much would you offer to send on to the other person?

Q34) How much would you keep ______ ?
Q35) How much would you offer to send ______ ?

b) Suppose the other person gets to decide how to divide the $10 between him or herself and you. How much do you predict that person would keep for him or herself and how much do you think he or she would send on to you?

Q36) Other person would keep _____

Q37) Other person would offer to send _____

[19] Subjects always responded to questions about amount kept (Q34, Q36, Q38 and Q41) in manners consistent with their answer to questions involving amount sent (Q35, Q37, Q39, and Q42).

The second situation involves what is referred to as an "ultimatum game." The subject is again asked to split a given amount of money. However, here the recipient of the offer may either accept it or reject it, in which case neither person gets anything. In this game, individuals playing according to game theory will offer the other player the minimum amount greater than zero. This offer should, according to the theory, be accepted as something is better than nothing. As with dictator games, however, actual behavior deviates from the predictions of game theory. Equal splits tend to be the modal response and the distribution of offers reflects less shading in favor of the player making the offer than is observed in dictator games – players realize that selfish offers might be viewed as "unfair" and that potential recipients may be willing to punish these transgressions by rejecting them.

Subjects were given this scenario and asked how much they would keep (Q38), what they thought the chances of their offer being accepted were (Q40), what they though the other person would keep if he or she got to decide on the division (Q41), whether they would accept the offer they expected the other player to make (Q43), and what the minimum offer they would accept was (Q44).

Situation 2

Now suppose you are in a situation in which $10 is, again, to be divided between you and another person. One of you will be asked to divide the money. Any division from $10 for you and $0 for the other person to $0 for you and $10 for the other person is allowed. <u>However, in this situation, the person receiving the offer can either accept it or reject it. If the offer is accepted, both of you receive the amounts agreed upon. If the person receiving the offer rejects it, neither of you receives anything.</u>

a) Suppose you get to decide how to divide the $10 between yourself and this other person. How much of the $10 would you keep and how much would you offer to send on to the other person?

Q38) How much would you keep ______ ?
Q39) How much would you offer to send ______ ?

Q40) Place a mark on the line below indicating what you think the chances of the other person accepting your offer are (for example, “a 10% chance”, ”a 50% chance”, “a 90% chance”).
|------------------------------------|------------------------------------|
0%   50%   100%

Suppose the other person gets to decide how to divide the $10 between him or herself and you. How much do you predict that person would keep for him or herself and how much do you predict he or she would offer to send on to you?

Q41) Other person would keep _____

Q42) Other person would offer to send _____

Q43) Would you accept this offer if the other person made it? (circle answer) Yes No

Q44) What is the minimum offer you would accept?_____

Mean, median and modal responses to each question for each group are shown in Table 10. Modal and median responses of the two groups are very similar. If we eliminate one VM from the calculation of the mean amount VM subjects demand in the ultimatum game and one NC from the computation of the minimum acceptable offer in the ultimatum game, the mean results across subject types are also uniformly similar to each other. In particular, the results are also consistent with members of both groups being sensitive to potential losses and having entirely accurate models of the minds of others.

Table 10

	Dictator - Subject Keeps	Dictator - Other Keeps	Ultimatum - Subject Keeps	Predict Probability Other Accepts Offer	Ultimatum - Other Keeps	Ultimatum - Subject Minimum Acceptable Offer
	Q34	Q36	Q38	Q40	Q41	Q44
NC Mean	$5.27	$5.76	$4.67	0.81	$5.33	$5.22 ($3.50)**
VM Mean	$5.00	$6.06	$5.26 ($4.65)*	0.89	$5.18	$3.18
NC Median	$5.00	$5.00	$5.00	0.90	$5.00	$5.00
VM Median	$5.00	$5.00	$5.00	0.99	$5.00	$4.00
NC Mode	$5.00	$5.00	$5.00	1.00	$5.00	$5.00
VM Mode	$5.00	$5.00	$5.00	1.00	$5.00	$5.00

* Mean if one VM subject who demanded $9.50 in the ultimatum but $0 in the dictator game is dropped from computation

** Mean if one NC whose minimum acceptable offer was $50 is dropped from computation.

Specifically, members of both groups wish to keep approximately $5 in the dictator game. Assuming both groups are aware of a sharing norm, the fact that VM subjects did not choose to keep more than NC subjects suggests they are as sensitive to the psychic costs of violating the norm as are NC subjects. Mean amounts kept by NC and VM groups in the ultimatum game ($4.67 and $4.65, respectively) are lower than the amounts they kept in dictator game ($5.27 and $5.00). This suggests members of both groups recognized the possibility that offers perceived as unfair in the ultimatum game might be rejected and responded to this possibility of incurring losses by moderating their demands.

Members of NC and VM groups expect that the other players will keep somewhat more than $5 ($5.76 and $6.06, respectively) – subjects predict that others will adhere to fairness norm but will shade the division a bit in their favor – and predict that others would moderate their demands in the ultimatum game (to $5.33 and $5.18, respectively).

Finally, minimum offers NC and VM subjects would accept in the ultimatum game are similar and non-trivial ($3.50 and $3.18). In summary, VM subjects appear no less sensitive to potential losses nor do they appear to lack accurate models of other players' minds. To formally confirm these conclusions, we conducted a MANOVA with subject type as a between-subjects factor and with subjects' responses to Q34, Q36, Q38, Q40, Q41 and Q44 as dependent variables. The between-subject effect of type is insignificant (Wilks' Lambda = .772, F(7,34) = 1.431, p=.225).

V. Discussion

The somatic marker hypothesis assumes that two processes inform our decisions. One involves deliberative, reasoned evaluation. The second is emotion driven. In individuals with ventromedial prefrontal cortex damage, Damasio (1994) hypothesizes that this latter process fails. In complex decision tasks, this failure leads to indecision – individuals with ventromedial prefrontal cortex damage simply can't do the estimations and computations needed to "compute" a solution and, unlike normals, have no auxiliary emotion-based process to fall back on.[20] In situations simple enough to be resolved

[20] There is no evidence that VM subjects were any less decisive than NC in our experiments. On the contrary, a larger number of NC failed to answer questions in the experiments overall.

through deliberation the lack of emotion-based input to the decision process results in risk seeking, impatience, and social incompetence.

The results of our experiments appear to contradict these predictions. In the context of our risky choices, VM and NC subjects appear very similar in terms of their overall propensity to seek risk, the features of gambles that they find particularly attractive or unattractive, and in terms of the mechanics they employed to arrive at their decisions. Given our intertemporal choices, VM subjects appear no more impatient than NC and are as sensitive to opportunities to anticipate and savor events. Finally, in our problems involving social interactions, VM subjects are no more likely to choose socially inappropriate though personally advantageous strategies than normals, no less sensitive to the prospect of potential losses and as adept as NC subjects at accurately predicting other players' behavior.

To understand why our findings are so at odds with those predicted by the Somatic Marker hypothesis it is instructive to compare aspects of our experiment with Bechara et al's (1994) Iowa gambling task – the results of which appear to confirm the Somatic Marker hypothesis.

Recall that normal controls in the Iowa gambling task initially experiment -- selecting cards from both the high-reward, high-penalty decks and the low-reward, low-penalty ones. As experience with high penalties accumulates, their selections become biased toward the low-reward, low-penalty ones and they develop anticipatory skin conductivity responses to consideration of the high-reward, high-penalty decks. VM individuals, in contrast, never learn to shy away from the high-reward, high-penalty decks and never develop SCR to them. Damasio (1996) interprets the development of anticipatory SCR (and assumed ventromedial prefrontal cortex activation) among NC but their absence among VM subjects as evidence that the high-reward, high-penalty decks have been assigned negative somatic markers in the former group but not in the latter.

Subsequent experiments support aspects of this inference. Rogers et al (1999), repeatedly presented subjects with binary choices between high-probability low-gain options and low-probability high-gain ones while scanning subjects' brains using FMRI. For each choice, subjects were told that a yellow token had been hidden inside one of six boxes displayed on a computer screen. Between 3 and 5 of the boxes were red with the remainder being blue. If the token was in a red box, the subject won a small number of abstract points. If the token was in a blue box, the subject won a large number of abstract points. Subjects had to decide whether they wanted to bet on the token being in the red or blue box. Consistent with the Somatic Marker hypothesis, Rogers et al report evidence of ventromedial prefrontal cortex activation during these decisions.

Critchley et al (2001) repeatedly presented subjects with a playing card valued 1 (ace) through 10. After each presentation, subjects were asked to predict whether the value of a card to be turned over subsequently would be greater or less than the one seen. Subjects played 100 rounds, receiving a 50 pence reward when their prediction matched the actual outcome and a 1 pound penalty when the predicted and realized outcomes differed. Subjects' brain activity was measured during the delay between the time subjects' made their predictions and the time the actual value of the predicted card was revealed. Consistent with Bechara et al's finding that normal subjects appeared to exhibit anticipatory emotional responses in the Iowa gambling task, Critchley et al's subjects exhibited ventromedial prefrontal cortex activation in the period between making their predictions regarding the value of the next card and the realization of that value.

Breiter et al (2001) presented subjects were a pie chart divided into three equal pieces each labeled with a different dollar prize value. Subjects watched as an electronic spinner superimposed on the pie traversed its sectors. FMRI images of brain activation were taken during these "anticipatory" periods as well as in the periods immediately after the spinner stopped and the reward/penalties were incurred. Subjects exhibited ventromedial brain activation in both anticipatory and outcome phases of the experiment.

In summary, there are a number of studies of brain activation containing evidence consistent with the Somatic Marker hypothesis. There are, however, other experimental findings that, like ours, contradict the hypothesis. Rustachini et al (2002) conducted an FMRI study in which subjects' brains were scanned while they made binary choices between different alternatives. Some options involved a certain payoff while others involved lotteries described as payoffs contingent on drawing a red or blue ball from an urn containing 180 balls. Some of these options were risky in that they offered specified probabilities of winning specific prizes. Others were ambiguous or uncertain in the sense that subjects were not told what the probabilities of winning prizes were and still others were what the authors referred to as "partially ambiguous" -- subjects had some but not complete information about the composition of red and blue balls in the urn. Subjects were given choices between all combinations of types of lotteries. While the authors found interesting differences in brain activation depending on the types of options involved in the decision – none of the decisions involved ventromedial prefrontal cortex activation.

Taken together these findings enable us to identify which differences in experimental design make a difference in terms of revealing discrepancies between VM and NC subjects and indicating the role of emotion in choice as summarized in Table 11. Let us first consider differences that don't appear to make a difference, beginning with the distinction between risk and uncertainty. The lottery questions we posed to subjects all involve choices under risk -- the probabilities of events occurring are precisely known. In contrast, choices in the Iowa gambling experiment are initially made under ignorance (subjects have no information on what the probabilities associated with outcomes are), then uncertainty (they have imprecise information about the probabilities) and only, perhaps, at the end of the game under risk. If this risk-uncertainty difference is responsible for the difference in findings between our study and Bechara et al's (1994), we shouldn't have seen ventromedial prefrontal cortex activation in Rogers et al (1999), Critchley et al (2001) and Breiter et al (2001) – all of which involve risk - but we do. Symmetrically, we should have observed activation in Rustichini et al's (2002) choices involving ambiguous lotteries, but we don't. Finally, the similarity between VM and NC subjects' intentions and expectations in our dictator and ultimatum games, games that inherently involve uncertainty about other peoples' likely behavior, argues against the risk-uncertainty distinction being important.

A subtler difference between our study and Bechara et al's concerns the representation of choices. In our study, subjects were presented with lotteries involving numerically specified prizes and probabilities. Probabilities in Bechara et al are, at best implicit (i.e., even after subjects learn what their values are.) A number of researchers have explored the possibility that the difficulties individuals with ventromedial damage

Table 11

		Studies →	Leland/Grafman	Rustachini et al	Bechara et al	Rogers et al	Critchley et al	Breiter et al
Hypothesized Source of Difference in Results[1]		VM Activation →	NA	No	NA	Yes	Yes	Yes
Risk vs Uncertainty			Risk	Both	Uncertainty	Risk	Risk	Risk
Representation of Risk / Uncertainty			Explicit	Both	Implicit	Implicit	Implicit	Implicit
Feedback / No Feedback			No Feedback	No Feedback	Feedback	Feedback	Feedback	Feedback
↳	Learning / No Learning		No Learning	No learning	Learning	No learning	No learning	No learning
	Exciting/ Boring		Boring	Boring	Exciting	Exciting	Exciting	Exciting
	Incentives/ No Incentives		No	Yes	No	No	Yes	Yes

encounter stem not from problems with the evocation of emotion but from an inability to fully and stably structure decisions. Goel et al (1997), for example, examined the recommendations VM and NC made in a financial planning task involving advice to a young couple on how to budget for the purchase a home while saving to put their children through college and retire. They found that VM subjects spent more time and had greater difficulty structuring the problem than normals – and arrived at very simple, non-compensatory, and sometime nonsensical solutions (e.g., eliminating shelter expenses, which would have a large impact on savings, by living in a tent.) Similarly, Goel and Grafman (1997) found that VM subjects had significantly more difficulty solving Tower of Hanoi problems and, in particular, had difficulty implementing moves that, while apparently at odds with the final objective, were efficient.

To the extent that the problems VM subjects encounter in making decisions result from inability to structure decision problems, it would not be surprising if their choices were more in line with normal controls in more structured tasks like ours than in less structured ones like Bechara et al. However, when taken together the results from the other studies summarized here don't support this possibility. In Rogers et al (1999), the probabilities associated with prizes are not numerically stated. Instead they are implicit in the description of the problem -- when there are 4 red and 2 blue boxes, the probabilities of the yellow marker being in a red or blue box are implicitly 2/3rds and 1/3rd, respectively. Likewise, in Critchley et al (2001) the probability associated with the next card drawn being of greater or lesser value than the target card is implicitly defined by the value on the target card. Both these studies report ventromedial activation. On the other hand, in Breiter et al (2001), the spinner rotating over a circle divided into three equal pie-shaped areas implicitly defines the probabilities of the three possible outcomes as equal to 1/3, ventromedial prefrontal cortex activation occurs, but there is no choice and thus no obvious “problem structuring” demand. Likewise, if the ventromedial prefrontal cortex is critical to problem structuring absent well-defined probability information, it should have been activated in those choices involving ambiguous lotteries in Rustichini et al (2002), but it wasn’t.

A third difference between our experiment and Bechara et al’s is the absence/presence of feedback. Feedback could serve two purposes. First, it might enable subjects to learn about the choices – learning that depends critically on emotion. However, if the role of the ventromedial prefrontal cortex in decision making is to expedite or enable learning, it should only be activated when there is something to learn – i.e., when the choices involve uncertainty rather than risk – and the opportunity to learn – i.e., when there is repetition. But in the Rogers et al, Critchley et al and Breiter et al studies there is no uncertainty and in Rustachini et al, while some choices involve uncertainty, there is no repetition.

A second way the absence/presence of feedback might explain the disparity between our findings and those observed in the Iowa gambling task is that feedback is necessary if subjects are to experience emotions. Research examining the way emotions influence choice distinguishes between "expected emotions" and "immediate emotions." (Loewenstein and Lerner, 2003) Expected emotions are those feelings one anticipates experiencing as a result of the consequences of alternatives being realized. Feelings regarding the pleasure or pain associated with a given outcome or the elation or regret involved with knowing the consequence one would have received if one had chosen differently are examples of "expected emotions." They are, fundamentally, thoughts about as yet to be experienced sensations. "Immediate emotions," in contrast, describe the decision maker's emotional responses to current or recent consequences and/or their general emotional disposition at the time the decision is made.

Research examining how people form perceptions of risk illustrates how immediate emotional responses to consequences may influence decisions. A common finding in this literature is that people tend to overestimate the frequency of death associated with causes like plane crashes, homicide and nuclear power plant mishaps. (Lichtenstein, Slovic, Fischhoff, Layman, and Combs, 1978) This bias, in part, results from the vividness and emotional salience of these types of events.

Decisions are not only swayed by emotional responses to specific consequences but by the emotional state of the individual at the time the decision is entertained – an emotional state which may have resulted from factors completely unrelated to the task at hand. Fearful individuals are more pessimistic in their risk estimates and more risk averse in their choices than individuals not primed to be fearful. (Learner and Keltner, 2000 a,b) Along similar lines, individuals primed to be anxious tend to be more risk averse than unprimed decision makers, while those who were primed to be sad or angry are more risk seeking. (Raghunathan and Pham,1999)

In our experiments, there is no repetition and no realization of the outcomes of choices. In these circumstances there is little or no opportunity to develop "immediate" emotions of either a specific or general nature,[21] in which case decision may be solely a product of computation. If so, and so long as the problems were not too difficult, we might expect not to observe differences between VM and NC subjects – and we didn't.

In Bechara et al's gambling experiments, on the other hand, outcomes are experienced as gains and losses, albeit hypothetical ones and the game is repeated. These conditions encourage immediate emotional responses to specific alternatives (e.g., negative reactions regarding the high-risk decks) and general emotional responses in the form of excitement and anxiety. Indeed, Damasio (1996, pg. 212) describes the Iowa gambling task as "colorful, a far cry from the boring manipulations of most other such situations." That the behavior of individuals with ventromedial prefrontal cortex damage and normal subjects diverge in these settings, and do so even after the representation of the options is understood, suggests that it is "immediate" emotions that people with ventromedial prefrontal cortex damage don't experience.

Findings in the other studies reviewed here are in accord with this explanation. Rogers et al (1999), Critchley et al (2001) and Breiter et al's (2001) tasks all involved immediate feedback regarding gains and losses necessary to generate emotional

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[21] That some of the questions do require subjects anticipate their own and others' "expected" emotions and that, for these questions, responses do not differ, suggests that the ventromedial prefrontal cortex does not mediate "expected" emotions.

responses.[22] In contrast, Rustichini et al's (2002) subjects only played out a subset of their choices and only did so after they had completed the decision task – there was no ongoing feedback regarding gains and losses and no significant activation the ventromedial prefrontal cortex nor in the amygdale --regions of the brain associated with the processing of emotion. Instead, they observe significant activation in regions in the parietal lobes - regions commonly activated in tasks involving both approximate and exact calculation.

[22] Critchley et al (2001)) and Breiter et al's (2001) experiments provided real monetary incentives. Rogers et al (1999) only involved winning and losing "abstract" points. The fact that ventromedial activity was observed in all three suggests that what is important to engage emotion in the decision process is excitement. This, in turn, explains a puzzling finding in Camerer and Hogarth (1999); namely, that financial incentives appear to improve performance in (*boring*) judgment and decision making experiments but not in (*exciting*) market and game experiments.

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