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Dissociable elements of human foresight: a role for the ventromedial frontal lobes in framing the future, but not in discounting future rewards

Lesley K. Fellows *, Martha J. Farah

Center for Cognitive Neuroscience, University of Pennsylvania, 3720 Walnut St., Philadelphia, PA 19104, USA

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Abstract

Impaired future thinking may be a core aspect of impulsive decision making. Recent efforts to understand the brain processes that underlie impulsivity have suggested a role for the frontal lobes. However, future thinking is unlikely to be a unitary process, and the frontal lobes are not a homogeneous entity. The present study contrasted the effects of dorsolateral and ventromedial frontal lobe damage on two distinct aspects of future thinking in humans. Temporal discounting, the subjective devaluation of reward as a function of delay, is not affected by frontal lobe injury. In contrast, a normal future time perspective (a measure of the length of an individual's self-defined future) depends on the ventromedial, but not dorsolateral, frontal lobes. Furthermore, investigation of the relationship of these two measures with classical symptoms of frontal lobe damage indicates that future time perspective correlates with apathy, not impulsivity. Apathy may deserve more attention in understanding both impaired future thinking and the impaired decision making that may result.

Keywords: Ventromedial prefrontal cortex; Dorsolateral prefrontal cortex; Lesion; Decision making; Impulsivity; Apathy

1. Introduction

The making of poor choices is characteristic of several disorders, ranging from substance abuse, to attention deficit hyperactivity disorder (ADHD), to frontal lobe damage (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Dolan, Denburg, Hindes, Anderson, & Nathan, 2001; Evenden, 1999; Kirby, Petry, & Bickel, 1999). A common theme of impaired impulse control may link these disparate conditions, which in turn suggests the possibility that they share a common neural basis. However, impulsivity is a variably defined construct that encompasses several distinct factors, and that are presumably manifestations of different brain processes (Evenden). Virtually all definitions of impulsivity include the idea of impaired cognition about the future, whether as impaired awareness of the future, or use of information about the future, or consideration of the future consequences of present actions. In the words of Bechara and co-workers, the poor decision making that may follow ventromedial frontal lobe (VMF) damage seems to reflect a "myopia for the future"(Bechara et al., 1994; Bechara, Tranel, & Damasio, 2000). One way of dissecting this complex behavioral phenomenon is by identifying dissociable features of poor impulse control in humans with focal brain damage.

A clearer understanding of any impairments in future thinking in patients with focal frontal lobe damage is directly relevant to elucidating the underlying brain processes, and has potentially broad implications for understanding disorders with similar behavioral profiles, but in which the underlying neuropathology is much less clear. The existing evidence for a role for the frontal lobes in future thinking, drawn from studies of decision making, is at best either indirect (Bechara et al., 1994; Bechara, Tranel, et al., 2000; Goel, Grafman, Tajik, Gana, & Danto, 1997) (Miller & Milner, 1985), or rests on single case reports (e.g. (Ackerly, 1950/2000) and see reviews by (Atance & O'Neill, 2001; Loewenstein, Weber, Hsee, &

* Corresponding author. Present address: Montreal Neurological Institute, 3801 University St., Montreal, Que., Canada H4A 2L1.
Tel.: +1 514 398 2083; fax: +1 514 398 1338.
E-mail address: lesley.fellows@mcgill.ca (L.K. Fellows).

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Welch, 2001)). We undertook to directly assess two aspects of future thinking that may result in the ill-considered behavior that often follows frontal lobe damage: the first concerns how steeply rewards are devalued as their delivery is pushed into the future, a phenomenon known as temporal discounting, while the second concerns the perceived dimensions of future time, sometimes labeled 'future time perspective'.

Weighing future outcomes requires comparing relative reinforcement values across delays. A large body of research has demonstrated that organisms ranging from pigeons to people discount delayed reinforcement (reviewed in (Ainslie, 2001; Critchfield & Kollins, 2001)); 10 dollars today is worth more to most people than 10 dollars that will not be received for a month. The rate at which a reinforcer loses its value across a delay is relatively consistent within individuals, and can be described by a hyperbolic function (Ainslie; Kirby & Herrnstein, 1995; Madden, Begotka, Raiff, & Kastern, 2003; Mitchell, 1999). Some pathological forms of impulsive behavior have been related to steep discounting functions: cigarette smokers, problem drinkers, cocaine or heroin addicts, and individuals with ADHD are more likely than normal subjects to prefer smaller, immediate gains over larger, delayed rewards (Barkley et al., 2001; Bickel & Marsch, 2001; Coffey, Gudleski, Saladin, & Brady, 2003; Mitchell; Vuchinich & Simpson, 1998).

Future time perspective is a second aspect of future thinking that may also underlie some kinds of impulsive behavior. The development of future goals and plans occurs within a temporal framework, whether or not this window of time is explicitly specified (Atance & O'Neill, 2001). The dimensions of this window contribute to determining what priorities will be set and what anticipated outcomes, rewards, or punishments will be considered. Aesop's ant and grasshopper were both making appropriate future plans, but from the perspective of very different future time horizons. Similarly, when human subjects contemplate the future in an open-ended fashion, within any given context, the actual chronological time being considered varies across individuals. Measures of future time perspective have been shown to correlate with more adaptive profiles on personality inventories, and have been applied in a variety of populations as a method of assaying the capacity for forward thinking or future orientation (Kastenbaum, 1961; Lessing, 1968; Wallace, 1956). A foreshortened view of future time has also been linked to pathological impulsive behavior: Heroin addicts have a significantly shorter future time perspective than controls (Petry, Bickel, & Arnett, 1998).

Although these two aspects of future thinking seem similar, they are not equivalent. Future time perspective measures a spontaneously chosen time horizon, which would not necessarily affect the way a person evaluates an event at a specific time in the future when explicitly cued to do so. Similarly, the rate at which reward decays across a specified delay may differ across individuals, even if they have a similar future time perspective.

How are these aspects of future thinking instantiated in the brain? Decades-old observations that frontal lobe damage inclines patients to 'live in the here and now' (e.g. (Ackerly, 1950, 2000) have been bolstered by more recent experimental work that has indirectly suggested a role for the frontal lobes in general (Goel et al., 1997), and the VMF in particular in various kinds of future thinking. Damage to ventromedial prefrontal cortex may lead to personality change marked by impulsive behavior and poor decision making. It has been claimed that these patients make poor decisions in a laboratory gambling task because they neglect future consequences (Bechara et al., 1994; Bechara, Dolan, & Hindes, 2002). Given that the assessment of future consequences hinges on both the conception of future time, and the discounting of future reinforcers, we asked whether damage to the VMF systematically impairs either process. We were also interested in whether these two constructs were dissociable, a finding that would suggest that they measure distinct aspects of impulsivity. Because the experience of suffering a brain injury might, in and of itself, lead to changes in future thinking, control data were acquired from both age-matched normal individuals, and a group of patients with brain lesions that spared the frontal lobes. In order to determine whether deficits in future thinking were a specific effect of VMF damage, or a more general effect of frontal damage, we also evaluated a group with dorsolateral frontal lobe (DLF) damage.

2. Methods

2.1. Subjects

Background information about the participants is provided in Table 1. Normal controls had no history of neurologic or psychiatric disease, closed head injury, or substance abuse, and were not taking psychoactive medication. Controls passed a screening neurological examination and scored at least 28/30 on the Folstein mini-mental state examination. ANOVA revealed no significant difference between

Table 1
Background information (mean (S.D.))

Group	Age (years)	Education (years)	IQ estimate	BDI score	Lesion volume (cm^3)
CTL (n = 26)	56.8 (14.7)	15.2 (2.8)	122 (9.9)	5.4 (4.4)	
VMF (n = 12)	54.5 (10.7)	13.5 (2.3)	118 (8)	9.2 (7.7)	23 (29)
DLF (n = 13)	61.3 (11.2)	15.6 (2.7)	120 (11)	9.0 (3.2)	19 (20)
NOF (n = 13)	59.6 (12.7)	13.5 (4.0)	119 (9.7)	9.6 (6.7)	23 (15)

the groups with regard to age or IQ estimated by the American version of the National Adult Reading Test (all *P*-values > 0.47). Group differences in education and Beck Depression Inventory (BDI) scores approached significance (education: $F(60,3) = 2.0$, $P = 0.13$; BDI: $F(57, 3) = 2.5$, $P = 0.07$). BDI scores tended to be lower in controls than in patients and were similar in all three lesion groups. The educational level of normal controls was well-matched to the DLF group, while the VMF group was best matched by the non-frontal lesioned (NOF) control group on this variable (see Table 1).

The areas of the brain damaged in each patient group are shown as overlap images in Fig. 1. Patients were assigned to the frontal group if damage principally involved cortex anterior to the precentral sulcus, and to the NOF group if the damage principally involved cortex posterior to the central sulcus. The frontal subgroups approximately follow the boundaries laid out in (Stuss & Levine, 2002), with VMF damage involving primarily medial orbitofrontal and/or ventral medial prefrontal cortex, and the DLF group including all patients meeting criteria for frontal damage, but sparing the VMF area. As can be seen in Fig. 1, the DLF group was primarily composed of subjects with damage to the inferior and/or middle frontal gyrus.

Mean lesion volumes were similar in the three patient groups (ANOVA: $F(2, 33) = 0.13$, $P = 0.88$). Lesions were secondary to rupture of anterior communicating artery aneurysms in 8 of 12 VMF subjects, and to ischemic stroke in 4. Lesions in the DLF group were due to ischemic or hemorrhagic stroke in 11 cases, and to resection of low-grade astrocytoma followed by local radiation therapy in 2. All NOF lesions were due to stroke. All lesions had occurred at least 6 months prior to testing (mean 3.4 (S.D. 2.9) years, range 0.5–10 years). There was no significant difference in the chronicity of the lesions across the three patient groups (ANOVA, $F(2, 35) = 0.16$, $P = 0.85$). Five of 12 VMF subjects, 7 of 13 DLF, and 8 of 13 NOF subjects were taking 1 or more psychoactive medications. These were most commonly anticonvulsants or antidepressants. One VMF subject was taking methylphenidate and two were taking acetylcholinesterase inhibitors. One DLF subject was taking lithium, one NOF subject risperidone.

Subjects with brain damage were administered a short neuropsychological battery for screening purposes. Selected results from this screening are provided in Table 2.

2.2. Tasks

The temporal discounting rate for money was estimated with a computerized task, following published methods (Kirby & Marakovic, 1996; Kirby et al., 1999; Monterosso, Ehrman, Napier, O'Brien, & Childress, 2001). Subjects chose (hypothetically) between various amounts of money now, and larger amounts delayed by 7–180 days. The pattern of their choices across 27 trials allowed estimation of the delay discounting rate according to the following formula: $V = v/(1 + kD)$, where V is the current (relative) value, v the absolute value, and D the delay. The steepness of discounting is expressed by the constant, k. The larger the value of k, the more a subject was inclined to choose smaller immediate amounts over larger, later amounts.

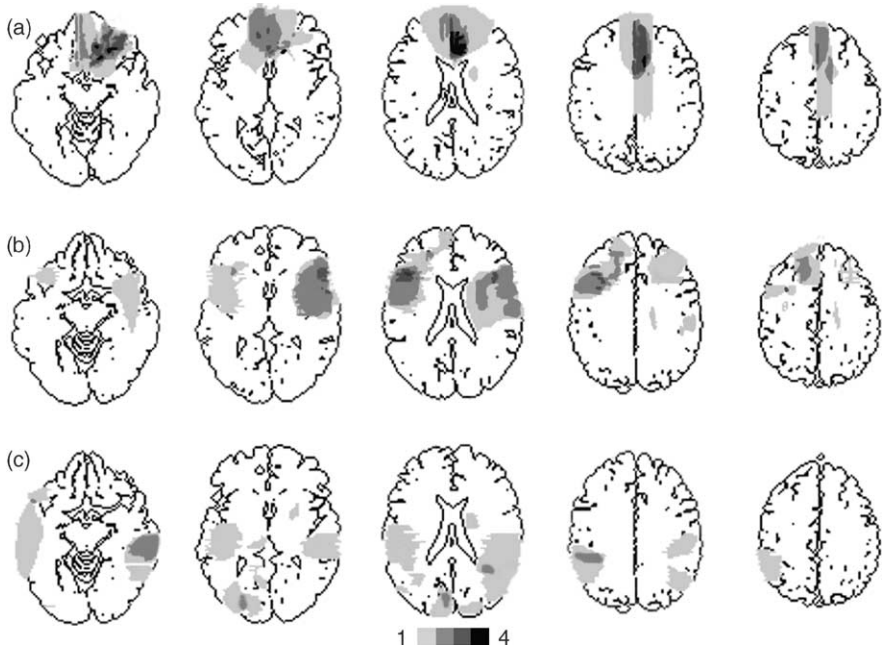

Fig. 1. Location and overlap of brain lesions. Panel a shows the lesions of the 12 subjects with ventromedial frontal damage, panel b those of the 13 subjects with dorsolateral frontal damage, and panel c those of the 13 subjects with non-frontal damage. Lesions are projected on the same five axial slices of the standard Montreal Neurological Institute brain, oriented according to radiologic convention. Areas damaged in only one subject are shown in light gray; darker shades denote the degree to which lesions involve the same structures in two or more individuals, as indicated in the legend.

Table 2
Results of selected neuropsychological screening tasks (mean (S.D.))

Group	Digit span forward	Animal fluency (in 60 s)	*F* fluency (in 60 s)	Verbal recall (1 min delay; correct/5)
NOF	5.8 (1.1)	14.1 (4.4)*	10.9 (4.70)	2.7 (1.4)
DLF	5.5 (1.1)	24.3 (9.6)	9.7 (5.3)	3.7 (1.1)
VMF	5.4 (0.9)	20.0 (6.7)	9.5 (5.5)	3.6 (1.4)

*Significant difference between groups, ANOVA, $P < 0.05$.

Future time perspective was measured with a task that asks subjects to generate a list of future life events, adapted from the method of Wallace (Wallace, 1956). The original task asked for 10 events. Given that our population was older, and that frontal lobe injury may impair the ability to generate lists spontaneously (e.g. as in fluency tasks), we asked for only five life events. The task was administered by the same experimenter, and with the same introduction and clarifications, for each subject. Specifically, subjects were told "Now I'd like you to spend some time thinking about your own future. Please think of five events that may happen to you in the rest of your life." Subjects answered orally, and were given non-specific encouragement after each event they reported. There was no time limit, and subjects were encouraged to 'keep thinking' until they had generated five events. Once the list was generated, the experimenter asked the subjects to estimate how far into the future each event would occur. In keeping with the recent literature (Petry et al., 1998), the two dependent measures for this task were 'extension', which is the maximum length of time generated by each subject, and the mean future time period for all five items. A content analysis was also performed by an investigator blind to the subject's lesion location.

2.3. Scales

We were interested in how these potentially dissociable aspects of future thinking might relate to everyday behaviors, particularly those behaviors that have been linked to the ventromedial frontal lobes. We administered two self-report questionnaires evaluating selected behaviors that are commonly associated with VMF damage. The Barratt Impulsiveness Scale (BIS-11) was designed to measure impulsivity as a personality trait and has been validated in psychiatric clinical populations (Patton, Stanford, & Barratt, 1995). The apathy scale is a 14-item questionnaire that was originally validated in patients with Parkinson's disease, but that has also been shown to have high intra- and inter-rater reliability in other neurological conditions, including stroke (Starkstein et al., 1992). This scale is based on a more detailed scale developed by Marin (Marin, Biedrzycki, & Firinciogullari, 1991); the items focus primarily on lack of motivation and initiative, rather than on the blunted emotional reactions that are sometimes considered to be a feature of apathy. Although scores on this scale can range from 0 to 42, the study in 50 patients with Parkinson's disease found a bimodal distribution, with scores of 14 or greater identifying patients with a clinical diagnosis of apathy with good sensitivity and specificity. The mean apathy score in the apathetic group in that study was 14.8, while the mean in the non-apathetic group was 5.5.

2.4. Statistical analysis

The temporal discounting constants (k) measured with the temporal discounting task were normally distributed following log-transformation, so comparisons were made with unpaired Student's *t*-tests. Dependent measures in the future time perspective task did not conform to a normal distribution, even following log-transformation (Shapiro–Wilk test, all $P < 0.01$). Non-parametric statistical tests were therefore used for these data.

We were interested in testing the directional hypothesis that VMF damage would result in an impulsive profile of a shorter future time perspective, and more steeply graded temporal discounting curves. We further planned to clarify whether such findings, if present, represented a specific effect of VMF damage, by asking whether damage to the frontal lobes that spared VMF, or damage sparing the frontal lobes entirely would result in the same phenomenon. For each of the two future thinking measures, planned pair-wise comparisons assessed the presence of a non-specific effect of brain injury by contrasting NOF controls to healthy controls. To control for any such non-specific effect, the performance of VMF subjects was compared to the NOF group. A parallel set of comparisons between the DLF and NOF groups was undertaken to evaluate the neuroanatomical specificity of any effect of frontal damage. Given that in each case, the hypothesized effect was directional, that is, we planned to test specifically whether the experimental groups had shorter future time perspectives, and/or steeper temporal discounting rates than the control groups, the significance level was set at $P < 0.05$, (one-tailed). The accepted *P*-value for unplanned contrasts and correlations was $P < 0.05$, (two-tailed).

3. Results

The rate at which the subjective value of a reward decays with delay was measured with a computerized temporal discounting task, which permits an estimate of the temporal discounting constant (k). VMF damage was not associated with steeper temporal discounting than NOF damage. Indeed, the mean temporal discounting rates were very similar across all groups. Because the discounting constants describe a hyperbolic function, summary data are typically presented as geometric means (Bickel & Marsch, 2001; Kirby et al., 1999;

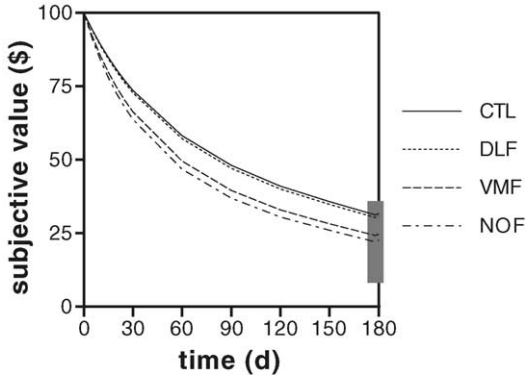

Fig. 2. Geometric mean temporal discounting curves for a hypothetical US$ 100 amount, for all four groups. The gray bar indicates the 95% confidence interval for the NOF control group. Temporal discounting rates are not significantly different across groups (see text)).

Monterosso et al., 2001). This mean discounting constant, k, for each group was: VMF 0.017, DLF 0.012, NOF 0.019, CTL 0.012. That is, US$ 100 in 6 months would be of subjectively equal value to US$ 34 now for the CTL and DLF groups, US$ 32 for VMF subjects, and US$ 27 for the NOF groups. Fig. 2 shows temporal discounting curves for the four groups. These curves show how rapidly US$ 100 loses its value, as a function of delay, based on the (geometric) mean discounting constant for each group. The range of *k* values was wide in all groups, as shown in Fig. 3. Pair-wise comparisons using Student's *t*-test showed no significant increases in *k* when comparing either frontal group to the NOF control group (all $P > 0.23$, one-tailed). The steepest discounter amongst all participants was the VMF subject with the most extensive lesion. However, there seemed to be no consistent relationship between lesion size and *k* value in the VMF group otherwise, or in the frontal group as a whole (Spearman ρ for VMF group: 0.14, $P = 0.66$; for combined VMF/DLF group: $\rho = 0.07$, $P = 0.74$).

This task has not previously been used in subjects with brain injury. One way to verify that participants understood the task is to examine the internal consistency of the choices. Although each choice in the task is unique, each level of discounting is represented three times. Further, choices should consistently favor the immediate option for *k* values less than the indifference point, and the later option for *k* values larger than the indifference point. It was thus possible to count the number of inconsistent responses. The mean number of inconsistent responses was small, and did not differ significantly across groups (VMF 1.8 ± 1.9, DLF 1.0 ± 1.0, NOF 1.2 ± 1.5, CTL 1.0 ± 0.8; Kruskal–Wallis test $H = 1.2$, $P = 0.75$), arguing that the subjects we tested were able to perform the task.

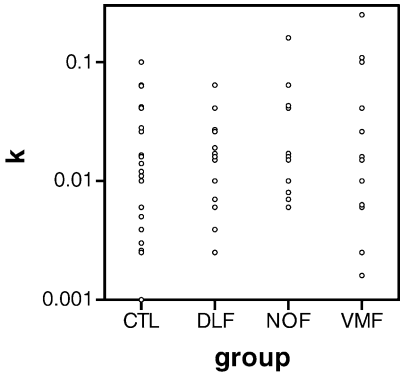

Fig. 3. Distribution of temporal discounting constants, *k*, for all subjects.

In keeping with the existing literature using the future time perspective task, two measures were made: extension (time of most distant life event), and mean personal future time (for all five events) (Petry et al., 1998). All subjects were able to perform this task; there was neither any difference in the number of future events generated (see Table 3, Kruskal–Wallis test, $H = 2.8$, $P = 0.42$), nor any evident difference in the content of events across groups. The most common types of events included future personal illness or death, family events (e.g. marriages or graduations), personal landmarks (e.g. buying a house or getting a new job) and wishful thinking (e.g. winning the lottery). The number of responses in each of these categories was not systematically different across groups ($\chi^2 = 5.8$, $P = 0.76$). The valence of the events was positive in the majority of cases (overall 83% of events were positive), and again the distribution of positive- and negative-valenced events was not systematically different across groups ($\chi^2 = 1.0$, $P = 0.79$).

The data suggest a non-specific reduction in future time extension as a result of the experience of brain injury: NOF subjects had a significantly shorter future time extension than normal controls (Mann–Whitney $U = 111$, $P < 0.05$, one-tailed). This finding confirms that comparison of the NOF group with each frontal group is most appropriate for testing hypotheses about specific effects of focal frontal damage. The group with VMF damage had a significantly foreshortened personal future time perspective compared to patients with lesions sparing the frontal lobes (Table 3). The mean outer limit of spontaneously generated personal future time (i.e. extension) was only 5.6 years for the VMF group, significantly less than the 10 years projected by the NOF group ($U = 44$, $P < 0.05$, one-tailed). DLF subjects did not have a significantly shorter future time extension than the NOF group. As might be expected from this pattern, a direct comparison of DLF

Table 3
Future time perspective measures in years (mean (S.D.)) for subjects with fixed lesions to different brain areas, and age-matched controls

Group	Future time events	Future time perspective extension (years)	Mean future time perspective (years)
VMF	4.8 (0.6)	5.6 (7.5)[a]	3.0 (4.2)[a]
DLF	4.8 (0.6)	9.4 (7.4)	3.7 (2.5)
NOF	5.0 (0)	10.0 (11.3)[b]	4.6 (5.0)
CTL	4.9 (0.3)	13.0 (8.1)	5.6 (3.6)

[a] Significantly less than the NOF group.
[b] Significantly less than the normal control group, both Mann–Whitney *U*-tests, $P < 0.05$, one-tailed.

Table 4
Self-report measures of impulsivity and apathy

Group	BIS score	Apathy score
VMF	59 ± 11 (N = 11)	13.5 ± 8.1 (N = 6)
DLF	56 ± 7 (N = 13)	14.4 ± 2.7 (N = 4)
CTL	53 ± 7 (N = 21)	6.5 ± 5.3 (N = 14)

All scales were not completed by all subjects. Values are given as mean ± S.D., with the N for each measure in parentheses. The Barratt Impulsiveness Scale (BIS) has a maximum possible score of 112, with higher values indicating higher impulsivity. The apathy scale has a maximum score of 42, with higher values indicating worse apathy.

and VMF groups suggests a trend for more foreshortening with VMF damage (U = 49, P = 0.055, one-tailed).

A similar pattern of results was seen with the mean future time perspective measure: the VMF group had a shorter mean future time perspective than lesioned controls (U = 46, P < 0.05, one-tailed), while the DLF group did not (P = 0.3, one-tailed). There was a similar trend for the VMF group when compared to DLF subjects on this measure (U = 56, P = 0.11, one-tailed), and a trend for the NOF group to evidence a shorter future outlook than normal controls (U = 121, P = 0.08, one-tailed).

This study was not designed to examine laterality effects, and is underpowered to detect any. The VMF group in particular includes too few subjects with definitely lateralized damage to support even an exploratory analysis. The DLF group included six with unilateral right hemisphere damage, and seven with unilateral left hemisphere damage. The future time perspective extension and discounting k values were identical for these two groups (mean extension 9.4 years, mean k 0.018).

Table 4 shows the results of self-report measures of impulsivity and apathy, two behaviors that are associated with VMF injury, and that we hypothesized could be related to future thinking. There was a significant effect of group on apathy scale scores (Kruskal–Wallis test, n = 24, H = 8.1, P = 0.02), but not on Barratt Impulsiveness Scale (BIS) scores (n = 45, H = 3.3, P = 0.2). Post hoc Mann–Whitney U-tests indicated that apathy scores for the DLF and VMF groups were significantly different from the CTL group (P < 0.05), but not from each other (P = 0.99).

An exploratory analysis was undertaken to test for relationships between these measures of everyday behavior, and future time perspective (as measured by personal future time extension), and temporal discounting (as measured by k). The results are shown in Table 5. There was a strong negative correlation between apathy score and personal future time extension. In contrast, temporal discounting rate was more tightly correlated with impulsivity as measured by the BIS, although this estimate of the strength of the correlation did not reach significance. The same relationships also seem to hold within the normal control group and frontal group alone (controls: apathy score × future time extension, $\rho = -0.53$, P = 0.06, BIS × discounting k, ρ = 0.31, P = 0.16; frontal group: apathy score × future time extension, $\rho = -0.58$, P = 0.07, BIS × discounting k, ρ = 0.26, P = 0.21). Of the sub-scores of the BIS, temporal discounting was most closely correlated with the 'non-planning' form of impulsivity (as opposed to motor or attentional impulsivity (see (Patton et al., 1995)); ρ = 0.28, P = 0.06 in the group as a whole).

Table 5
Spearman rank order correlation (ρ) between foresight measures and scores on two self-report measures of behavior for all groups combined

	Future time extension (years)	Temporal discounting, k
BIS	−0.08 (P = 0.55)	0.25 (P = 0.09)
Apathy scale	−0.59 (P = 0.004)	0.03 (P = 0.88)

P values have not been corrected for multiple comparisons.

While there is a relationship between depressive symptoms detected by the BDI, and symptoms of apathy detected by the apathy scale (ρ = 0.48, P = 0.01), these scales do not seem to be measuring identical constructs in this population, replicating the findings in other patient groups (e.g. Starkstein et al., 1992). In contrast to the correlation between apathy score and future time extension, there was no correlation between BDI scores and future time extension in the group as a whole ($\rho = -0.09$, p = 0.45)), in the frontal group alone (future time extension: ρ = 0.06, P = 0.76), or the control group alone (ρ = 0.09, P = 0.62).

4. Discussion

Poorly considered choices may be a prominent feature following VMF damage (Bechara et al., 1994). However, the fundamental processes that underlie this deficit remain poorly understood. The performance of such patients on a laboratory gambling task has been interpreted as evidence for a neglect of future consequences, colorfully termed "myopia for the future" (Bechara et al.; Bechara, Damasio, & Damasio, 2000). While the evidence is indirect, the possibility that the VMF is a key mediator of future thinking led us to investigate this question with other tools.

The present study employed two different measures to evaluate future thinking in patients with VMF damage. Two major findings emerged: Surprisingly, VMF damage did not influence temporal discounting rates. In contrast, personal future time perspective was selectively foreshortened following VMF damage. This was not a non-specific effect of frontal damage: DLF subjects did not differ from controls on either measure of future thinking.

Temporal discounting is a well-studied phenomenon in normal human subjects (Ainslie, 2001; Kirby & Marakovic, 1996), and steep discounting (often termed 'myopia for future rewards') has been related to pathological forms of impulsivity in drug addiction and ADHD, for example (Barkley et al., 2001; Bickel & Marsch, 2001). The relatively stereotyped shape of temporal discounting curves and the presence of the same phenomenon in other species suggest the possibility of a definable neural substrate for this process. Efforts to investigate this issue in humans have focused on neurochemical systems: acute amphetamine administration leads to shallower

discounting (de Wit, Enggasser, & Richards, 2002) while tryptophan depletion has no effect (Crean, Richards, & de Wit, 2002) suggesting that dopamine and not serotonin may play a crucial role. To our knowledge, this is the first attempt to define the neural basis of this process at the anatomical level in humans. The absence of an effect of frontal damage in this relatively large group of subjects argues against a necessary role for the frontal lobes in the subjective valuing of future rewards.

The temporal discounting task we used might be faulted for its abstract, hypothetical design. However, future thinking is by necessity abstract, and often hypothetical. The preserved ability to make consistent, fine-grained judgments about the value of delayed rewards despite frontal lobe injury suggests that other facets of future thinking may be more relevant to explaining the short-sighted behavior of such individuals.

There are (at least) two ways of being 'short-sighted': one is by steeply discounting future reinforcement, and the second is not to look very far ahead when considering the future in any particular context. The results of the future time perspective task argue that VMF damage is associated with this second form of short-sightedness. Furthermore, this short-sightedness is more severe than that induced by the experience of suffering brain injury alone: The future time perspective of VMF subjects was significantly shorter than both normal and non-frontal lesion controls. This effect seems to be restricted to VMF damage; the performance of subjects with DLF damage did not differ from that of either control group. This measure relates to an individual's own future. It would be of interest to determine whether this deficit is present in other aspects of future thinking, such as thinking about the future of others. Goel et al. (1997) noted a tendency for subjects with frontal damage to focus on shorter-term goals than controls in a complex financial planning task that involved a fictitious family (Goel et al.), suggesting the possibility of a more general constriction of future thinking in such patients.

We chose to study these two aspects of future thinking because deficits in either or both would predispose to poor choices about delayed outcomes, a hallmark of VMF damage. That is, a future reward might be undervalued because of steep temporal discounting, or not considered at all if it would occur outside the 'future window' of the individual. Although deficits in both of these abilities have been found in drug addicts, the present study indicates that future time perspective and temporal discounting are dissociable, with VMF damage impairing the former, but not the latter.

A more mundane explanation for this dissociation in performance is that the temporal discounting task is simply less sensitive than the future time perspective task. Although we cannot entirely exclude this possibility, there are two lines of evidence that make it unlikely. First, our own data show no evidence of either a ceiling or floor effect in the discounting task (see Fig. 3), and performance of the control group is very similar to performance of normal subjects in the published literature (Kirby et al., 1999). Second, and most importantly, this task has successfully detected differences in temporal discounting in other populations, including heroin addicts (Kirby et al.), and cigarette smokers (Bickel, Odum, & Madden, 1999). The impulsivity of subjects with VMF damage is, if anything, more pronounced than the impulsivity of cigarette smokers. Therefore, if this task is able to detect this form of increased impulsivity in cigarette smokers, it seems likely that it would have adequate sensitivity to detect such impulsivity in subjects with outright frontal damage.

While changes in future time perspective may be relevant to understanding the real-life decision-making impairment demonstrated by subjects with VMF damage, it is not clear whether this finding has any bearing on understanding the impairments such subjects demonstrate on laboratory gambling tasks (Bechara, Damasio, Tranel, & Damasio, 1997; Bechara, Tranel, et al., 2000; Rogers et al., 1999). Indeed, we have found that the poor performance of VMF subjects on the Iowa gambling task is primarily due to impairments in flexible stimulus-reinforcement learning (Fellows & Farah, 2005).

The poor decision making of VMF patients has largely been framed in terms of impulsivity in the existing literature (Bechara et al., 1994; Bechara et al., 1997; Bechara, Tranel, et al., 2000). The neuroimaging literature on impulsivity has yet to yield consistent results, perhaps largely due to the heterogeneous experimental paradigms used to date, but it is notable that some of these studies have found that measures of individual differences in trait impulsivity related best to activation in anterior cingulate (Garavan, Ross, Murphy, Roche, & Stein, 2002) or lateral orbitofrontal cortex (Horn, Dolan, Elliott, Deakin, & Woodruff, 2003), rather than VMF.

Apathy may also be a prominent symptom following damage to medial frontal structures (Tekin & Cummings, 2002), and might also be expected to result in erratic, seemingly ill-considered choices. Our results suggest that apathy, rather than impulsivity, correlates much more closely with future time perspective. This must be treated as a preliminary finding for several reasons: impaired insight following frontal damage may affect the reliability of self-report measures, the impulsivity scale we used has not been validated in neurologically ill populations, and these data were only available for a subset of the total group. However, the association between future time perspective and apathy score was present even in the normal controls, for which many of these caveats do not apply. This is an intriguing association and deserves further study. Although both apathy and impulsivity have long been known to follow frontal lobe damage, apathy has received little attention in recent efforts to explain the poor choices of such patients. It may prove to be an important factor in understanding both abnormal future thinking, and the poor decisions that may result.

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