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Decision Making after Traumatic Brain Injury: A Temporal Discounting Paradigm

Rodger Ll. Wood,[1] AND Louise McHugh[2]

[1]Psychology Department, Swansea University, Swansea, Wales
[2]School of Psychology, University College Dublin, Dublin, Ireland

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Abstract

A temporal discounting paradigm was used to examine decision making for hypothetical monetary reward following traumatic brain injury (TBI). A case-control design compared individuals following moderate or severe TBI with a healthy control group matched for age and gender. The impact of intelligence, impulsivity, and mood on temporal discounting performance was examined. A within-subjects design for the TBI group determined the influence of a range of neuropsychological tests on temporal discounting performance. Both patients and controls demonstrated temporal discounting. However, the TBI group discounted more than controls, suggesting that their decision making was more impulsive, consistent with ratings on the impulsiveness questionnaire. Discounting performance was independent of neuropsychological measures of intelligence, memory, and executive function. There was no relationship between temporal discounting and ratings of everyday executive function made by patients' relatives. Low mood did not account for discounting performance. The results of this study suggest that temporal discounting may be a useful neuropsychological paradigm to assess decision making linked to monetary reward following TBI. Performance was relatively independent of intelligence, memory and standard tests of executive ability and may therefore assist when assessing a patient's mental capacity to manage their financial affairs. (*JINS*, 2013, *19*, 181–188)

Keywords: Brain injuries, TBI, Impulsive behavior, Neuropsychological tests, Executive function, Decision making

INTRODUCTION

Recent efforts to examine impulsivity in relation to decision making after traumatic brain injury (TBI) have broadly followed two paradigms (Marsh, Dougherty, Mathias, Moeller, & Hicks, 2002). One is a disinhibition-attention paradigm, where impulsivity is defined as making a premature response; described by Barratt (1994) as *ideomotor impulsiveness* (i.e., acting without thinking). A version of this was used by Miller (1992) who investigated impulsivity in relation to risk taking and the ability to synthesize fragmented information after frontal lobectomy. He found that both frontal and control groups obtained high risk-taking scores. However, the frontal group demonstrated impulsive behavior that reflected an impairment of inhibitory control rather than a desire to engage in risk, or impaired ability to estimate chances of success.

Another approach to measuring impulsivity has involved reward-choice paradigms, one version of which is the Iowa Gambling Task (IGT) (Bechara, Damasio, Damasio, & Anderson, 1994). This complex decision-making paradigm, in which subjects determine which cards might win or lose them money on the basis of feedback, was developed to identify abnormalities of executive functioning attributable predominantly to the ventromedial prefrontal cortex (Bechara et al., 1994, 2000; Buelow & Suhr, 2009). Studies found that patients with ventromedial lesions were unable to use somatic cues to guide decision making on the basis of recent experience or in conditions of uncertainty (Bechara, Damasio, Damasio, & Lee, 1999; Bechara, Damasio, & Damasio, 2003). One possible weakness of the IGT, however, is that performance only reflects decision making in the context of immediate feedback whereas, in the real world, decision making often requires judgments on outcomes that occur without immediate feedback and at different points in time. For this reason, another reward-choice paradigm, that of a *temporal discounting*, could be a more useful measure of impulsive decision making as the latter examines the extent to which the subjective value of a reward decreases as the delay until receipt increases.

The term *temporal discounting* refers to a tendency for some individuals to prefer smaller sooner rewards over larger

Correspondence and reprint requests to: Rodger Ll. Wood, Brain Injury Research Group, Department of Psychology, College of Human and Health Sciences, Swansea University, Swansea, Wales, SA2 8PP.
E-mail: r.l.wood@swansea.ac.uk

later rewards, which research has shown to be unaffected by real versus hypothetical rewards (Crean, de Wit, & Richards, 2000; Johnson & Bickel, 2002; Reed & Martens, 2011). The choice of a delayed larger reward is assumed to reflect self-control, while opting for an immediate smaller reward is said to exemplify poor judgment, largely as a consequence of impulsivity (Ainslie, 2001; Green & Myerson, 1993; Klapproth, 2011). Impulsivity is a frequent legacy of TBI, one which reflects a lack of inhibitory control, contributing to problems of behavioral self-regulation and social cognition, leading to poor social and financial decision making (Christ, White, Brunstrom, & Abrams, 2003; McAllister, 2007; Worthington & Wood, 2010).

Temporal discounting methods have been applied to substance abuse, attention deficit hyperactivity disorder, and problem gambling (see Critchfield & Kollins, 2001, for a review). However, there has been a relative lack of research investigating its impact following TBI. An exploratory study (McHugh & Wood, 2008) used a temporal discounting paradigm to examine decision making for hypothetical monetary reward in a group of patients following brain injury and age-matched controls. Participants were asked to choose between a larger reward available at a specified time in the future and smaller reward available immediately. Each of the two groups demonstrated temporal discounting; that is, the subjective value of the reward decreased with increasing delay before gratification. However, the TBI group discounted more than the controls, suggesting that their decision making was more impulsive, possibly reflecting a need for immediate gratification.

In their pilot study, McHugh and Wood (2008) controlled for estimated IQ between groups but did not examine relationships between decision making and cognition in general, particularly the role of executive ability. This was potentially an important weakness because research on adults with learning disability (Willner, Bailey, Parry, & Dymond, 2010) found that increased temporal discounting was related to executive functioning but not IQ. However, in a TBI group it can be difficult to distinguish executive disability from problems of general intelligence when assessing individuals with IQ < 80 (Duncan, Burgess, & Emslie, 1995). One possible way to resolve this would be to explore the role of memory, which mediates many aspects of decision making and executive function (Carpenter, Just, & Reichle, 2000). However, Shamosh et al. (2008) found that working memory failed to explain the variance in delayed discounting performance, beyond that explained by general intelligence. Another factor that can influence decision making is mood (Pfister & Bohm, 2008; Yuen & Lee, 2003; Zeelenberg, Nelissen, Breugelmans, & Pieters, 2008). This possibly relates to the findings of Drevets and Raichle (1998), which showed that several cerebral areas in the prefrontal system are important for decision making (e.g., anterior cingulate, ventral, and dorsolateral prefrontal cortex). All these areas, which are vulnerable to TBI, exhibit decreased activity during depressed states.

To examine the impact of these factors on decision making using a temporal discounting paradigm, we compared a new TBI sample against control participants matched for age and gender to (1) re-establish the impact of TBI on temporal discounting for monetary reward compared to controls; (2) to examine the influence of intelligence and impulsivity on discounting performance across groups; (3) to investigate relationships between discounting performance and neuropsychological tests of memory, and executive function; (4) to determine if performance on the discounting task was related to ratings of everyday executive dysfunction made by relatives of individuals following TBI; and (5) to determine whether mood can influence decision making in the context of a temporal discounting paradigm.

In line with our previous pilot study, we predicted: (1) that TBI participants would discount more steeply than non-injured controls but performance would be unrelated to intelligence; (2) that the TBI group would exhibit more impulsive decision making; (3) in line with Willner et al. (2010), we anticipated that there would be a relationship between temporal discounting and performance on executive tests in the TBI group, but not with other measures of cognitive ability; (4) that discounting performance would be related to ratings of everyday executive dysfunction made by relatives, and (5) we also expected to find that low mood would have a negative impact on temporal discounting performance.

METHOD

All human data included in this manuscript were obtained in compliance with the Helsinki Declaration and with the approval of the Department of Psychology Human Research Ethics Committee, Swansea University.

Participants

Ninety consecutive referrals to the Tertiary Head Injury Clinic at Swansea University for neuropsychological assessment and rehabilitation advice were invited to participate in this study. Patients had been referred on the basis that they had consulted their GP, or hospital specialist, because of executive-type problems in everyday behavior following TBI. Patients were excluded if the impression at clinical interview (conducted by R.L.W.), or performance on neuropsychological tests, threw doubt on their capacity to provide informed consent. Other exclusion criteria comprised a developmental history of learning disability recorded in GP or hospital records, or an estimated pre-accident level of intellectual ability <70, using the UK standardization sample for WAIS III Full-Scale IQ, Wechsler Test of Adult Reading (WTAR; The Psychological Corporation, 2001); a post-accident IQ < 80; a history of psychiatric illness, personality disorder, drug or alcohol abuse; previous head trauma, or a neurological disorder that could compromise ability to understand the test procedure. Fifty-one patients with TBI met these criteria (Males $N = 39$). Cases recruited or excluded from the study were drawn from the same socio-economic area, and no difference was recorded in terms of age, gender, injury severity, or time since injury ($p > .05$).

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None of the patients recruited for this study had been included in any previous study on temporal discounting.

In the TBI group, the mean time between injury and assessment was 3.12 years (*SD* = 2.21 years; range 1–7.32 years). Injury severity was determined by length of Post Traumatic Amnesia (PTA) obtained retrospectively (McMillan, Jongen, & Greenwood, 1996) (mean: 10.25 days; *SD* = 18.99; range, 1–82) and Glasgow Coma Scale scores (GCS; Teasdale & Jennett, 1974) at the time of hospital admission (mean: 11.32; *SD* = 3.24; range, 3–12). Twenty eight patients met both GCS and PTA criteria for severe injury (GCS < 8; PTA > 24 h). A further 10 patients only met the PTA criterion for severe injury. Thirteen were classed as moderate injuries based on a combination of GCS and PTA scores (GCS 8–12; PTA 1–24 h). However, irrespective of the formal classification of injury severity, all participants were reported by relatives to exhibit executive-type problems that had an impact on activities of daily living. Magnetic resonance imaging (MRI) scan data was available for 32 of the TBI group. Although injuries sustained in TBI are generally considered to be diffuse, it is also accepted that such injuries predominantly implicate the prefrontal cortex. The available neuroimaging data indicated that 12 patients *predominately* had left frontal lesions, 7 right frontal, and 5 bilateral involvement. Eight scans were "normal."

Mean age at injury was 33.37 years (*SD* = 11.32; range, 22–57) and at assessment, 37.33 years (*SD* = 8.35; range, 25–60). The cohort had achieved an average of 11.72 years of education (*SD* = 1.94; range, 7–15). Before injury, 93.5% were employed on a full-time or part-time basis, 2.2% were in education, 1.2% had retired, and 3.1% were unemployed. At the time of assessment, 34.4% remained in full or part time employment, 4.2% were in education, 8.7% had retired, and 52.7% were either unemployed or working as volunteers.

The patient group was compared to 51 healthy control participants comprising relatives and friends of the patients who accompanied them to their appointments, as well as "blue collar" university employees. All were subject to the same exclusion criteria as the patient group.

The two groups did not significantly differ in age at assessment (TBI mean 34.65; *SD* 14.54; control group 37.29; *SD* 14.07: $t[100] = -.93$, $p > .05$) or gender distribution ($\chi^2[1, N = 102] = 2.87$, $p > .05$). However, there was a significant difference between estimated intelligence in the control group, based on WTAR scores (mean 106.20; *SD* 6.50) and post-accident intelligence in the patient group, based on their full scale WAIS III scores (mean 91.63; *SD* 12.80; $t(100) -7.27$; $p = .0001$).

Design

The design of the study was a 2×9 mixed analysis of covariance (ANCOVA) design with group (control or TBI) as the between-subject factor, time delay (1 day, 2 days, 1 week, 2 weeks, 1 month, 3 months, 6 months, 9 months, and 1 year) as the within-subject factor, scores on the WTAR as a covariate, and level of discounting as the dependent measure.

Measures

Temporal discounting

The term *temporal discounting* refers to the tendency of individuals to prefer smaller sooner rewards (SSRs) over larger later rewards (LLRs). One widely used procedure to measure the rate of temporal discounting involves making a choice between an amount of money, hypothetical or real, that is available immediately and a larger amount that is available at a later date. For example, if presented with the choice between $85 now (the SSR) or $100 in 1 month (the LLR), some people would choose the SSR and be labeled *impulsive*, whereas those who prefer the LLR would be said to have exercised *self control* (e.g., Rachlin & Green, 1972). Findings to date indicate that behavior patterns are not substantially affected by real versus hypothetical rewards (e.g., Johnson & Bickel, 2002). Using this method, the SSR can be manipulated over successive trials, while the LLR is kept constant. The aim of this procedure is to identify the current subjective value of temporal rewards, defined as the magnitude of SSR that generates indifference in choice against the LLR (Critchfield & Kollins, 2001). This value is referred to as the *indifference point.*

In the current study, an automated discounting task was used to compare decision making of relative values in the face of short- and long-term rewards. All trial presentations were controlled by the computer, using a choice algorithm originally described by Richards, Zhang, Mitchell, and de Wit (1999). The participant was presented with an SSR and an LLR on the computer screen and was asked to make a choice between the two. Consistent with discounting paradigms, the SSRs were manipulated over successive trials, while the LLR was kept constant (Critchfield & Kollins, 2001). For the LLR, the algorithm gradually converged on the indifference point by using a random adjusting-amount procedure. This procedure used answers to previous questions to narrow the range of values from which the value for the next comparison was selected. An important feature of this method is that, to minimize the effects of subject error (e.g., due to inattention), the computer varied the magnitude of the smaller, more immediate reward according to a *double limit procedure*, which precluded any single answer from controlling the convergence toward an indifference point. Indifference points were calculated for one LLR (£100) across nine time delays (1 day, 2 days, 1 week, 2 weeks, 1 month, 3 months, 6 months, 9 months, and 1 year). The LLR-delay combinations were presented in a randomized order and all trials were presented in a single session. The time to complete all 9 trials ranged between 15 and 25 min.

Barratt Impulsiveness Scale (BIS II; Patton, Stanford, & Barratt, 1995)

This self-report questionnaire classifies impulsivity into one total score and three subscales: motor impulsivity, attentional impulsivity, and non-planning impulsivity. Higher BIS II scores indicate higher levels of impulsivity. All participants were required to complete the BIS II after completing the

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temporal discounting task. Good internal consistency coefficients and concurrent validity have been reported for total scores (Patton et al., 1995) and for the subscales (Stanford et al., 2009). To the authors' knowledge the psychometric properties of BIS II with a TBI population are unknown but the measure has been used to investigate personality and neurocognitive correlates of impulsive aggression in long-term survivors of traumatic brain injury (Greve et al., 2001) and in previous research on discounting performance after TBI (McHugh & Wood, 2008).

The Beck Depression Inventory, Second Edition (BDI-II; Beck, Steer, & Brown, 1996)

The BDI-II is a 21-item self-report instrument intended to assess the existence and severity of symptoms of depression as listed in the American Psychiatric Association's *Diagnostic and Statistical Manual of Mental Disorders* Fourth Edition (DSM-IV; 1994). When presented with the BDI-II, respondents are asked to consider each statement as it relates to the way they have felt for the past 2 weeks. There is a four-point scale for each item ranging from 0 to 3. Scores are cumulative, with higher scores indicating greater levels of depressed mood.

Neuropsychological tests

The measures used in this study were standard clinical tests of intellectual ability, memory function, and executive ability, routinely administered as part of the neuropsychological examination:-

Intelligence

- Wechsler Test of Adult Intelligence (WTAR; The Psychological Corporation, 2001): to obtain estimates of intellectual ability in the control group.
- Wechsler Adult Intelligence Scale – 3rd edition (WAIS-III) (Wechsler, 1997): to obtain a measure of current, post-injury intellectual performance in the TBI group. Subtests comprised: Vocabulary, Similarities, Comprehension, Digit Span, Arithmetic; Picture Completion; Picture Arrangement; Digit Symbol; Symbol Search; Matrix Reasoning.

Memory

The Wechsler Memory Scale – 3rd Edition, (WMS-III; Wechsler, 1997): administered to the TBI group to determine the influence of different memory functions on temporal discounting performance. Sub-tests comprised—Logical memory I & II; Face Recognition I & II; Verbal Paired Associates I & II; Family Pictures I & II; Letter-Number Sequencing; Spatial Span, and Auditory Recognition Delayed.

Executive Ability

Behavioral Assessment of Dysexecutive Syndrome (BADS; Wilson, Evans, Alderman, Burgess, & Emslie, 1997): all the sub-tests were administered to the TBI group to determine the influence of executive abilities on temporal discounting performance. Tests: Key Search, Zoo Map, Temporal Judgement, Modified Six Elements, Action Program and Rule Shift.

The Hayling Test (Burgess & Shallice, 1997): a measure of response initiation and response suppression consisting of two sets of 15 sentences, each with the last word missing. In the first section the examiner reads each sentence aloud and the participant has to complete the sentence, yielding a simple measure of response initiation speed. The second part of the Hayling requires subjects to complete a sentence with a nonsense word (and suppress a sensible one), giving a measure of response suppression and thinking time.

Dysexecutive Questionnaire (Wilson et al., 1997): a 20-item questionnaire included as part of the BADS, which describes a range of behavior associated with the dysexecutive syndrome. Ratings of frequency are made on a Likert-type scale (from "never" to "often"). There is one version for the respondent to use and a second version for a family member. To avoid problems associated with poor insight in the TBI group, the informant version (DEX-O) was used in the study.

Procedure

Participants sat in front of a computer with a 36-cm color monitor, and a standard computer mouse. Each participant was told to follow instructions that appeared on the screen:- *Each computer screen presents a task. Your job is to look at the details of each task and to try to make a choice from those available to you on the screen. You should use the mouse to click on what you think is the preferred choice for each task. The computer will then present the next task immediately. The computer will let you know when the study is over.*

Participants were instructed to attend to a box at the top of the screen which contained the caption "*Which would you prefer*" before each trial. Below this statement two other labels were presented, one displaying the SSR and the word "now" (e.g., "£50 now") and the other displaying the LLR and a specified delay (e.g., "£100 in 1 month"). The researcher remained in the room with the participants until they had responded to the first trial to ensure they knew what was involved in the task. The text in these boxes was shaded grey for 0.5s. Any response made during this time was ineffective. After this delay, the text color changed to black, at which point participants could respond by clicking either box. Once a choice had been made the screen was cleared in preparation for the next presentation.

RESULTS

Temporal Discounting Between Groups

The indifference point represents the mean value of the SSR that participants select over the LLR. The mean indifference point for each of the nine time delays for TBI and control participants is presented in Figure 1.

To determine whether there was a relationship between intelligence and time delay for the TBI (WAIS III) and the

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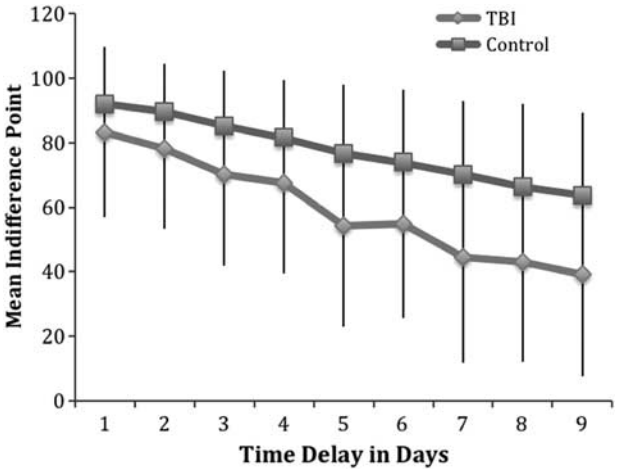

Fig. 1. Mean indifference points across the nine time delays for the traumatic brain injury (TBI) and Control participants.

control group (WTAR) a series of Bonferroni corrected correlations were conducted (adjusted p value .006). The correlations revealed that there was no significant relationship between intelligence and the indifference point at any of the nine time delays for either group. A mixed model analysis of variance (ANOVA), with group as the between subject factor, time delay (1 day, 2 days, 1 week, 2 weeks, 1 month, 3 months, 6 months, 9 months, and 1 year) as the within-subject factor, revealed a significant effect of time delay (F[8,792], 70.8; $p < .001$; $\eta_p^2 = .42$). There was also a significant effect of group (F[1,99], 19.84; $p < .001$; η_p^2 .17), and a significant interaction between time delay and group (F[8,792] 3.89; $p = .0001$; $\eta_p^2 = .04$). The interaction between time delay and group was further examined using a series of planned comparisons between indifference points for TBI and control groups across each of the nine time delays (using a Bonferroni corrected alpha level < 0.006). The results presented in Table 1 suggest that the patient group not only discounted at a higher rate but that discounting increased as the time delay increased.

Area Under the Curve

A theoretically neutral method, the *area under the curve* (Myerson & Green, 1995), was also used to calculate discounting. This is not tied to any one conceptualization of the mathematical form of the discounting function. To calculate the area under the curve, the delay and subjective value (i.e., the point at which the subject switched from an LLR to an SSR) for each data point was first normalized. The delay was expressed as a proportion of the maximum delay, and the subjective value was expressed as a proportion of the nominal amount. These normalized values were used as x and y coordinates respectively, to construct a graph of the discounting data. Vertical lines were then drawn from each data point to the x-axis, subdividing the graph into a series of trapezoids. The area of each trapezoid is equal to $(x_2 - x_1)[(y_1 + y_2)/2]$, where x_1 and x_2 are successive delays, and y_1 and y_2 are the subjective values associated with these delays (N.B., for the first trapezoid, the value of x_1 and y_1 are set at zero and one). The area under the empirical discounting function is equal to the sum of the areas of these trapezoids. The amount of discounting ranges between one (no discounting) and zero (total discounting).

Table 1. Between group (TBI versus control) time delay comparisons for mean indifference point across each of the nine time delays

Time delay	t value	p value
1 Day	−2.09	0.04
2 Days	−2.79	0.01
1 Week	−3.19	0.002
2 Weeks	−2.91	0.004
1 Month	−4.07	0.0001
3 Months	−3.67	0.0001
6 Months	−4.51	0.0001
9 Months	−4.12	0.0001
1 Year	−4.26	0.0001

The mean and standard deviation area under the curve (AUC) data for the TBI and control groups are as follows TBI: $M = .48$; $SD = .26$; Controls: $M = .70$; $SD = .21$. A correlational analysis in the TBI group failed to find a significant relationship between WAIS III scores and AUC (r[51] = 0.26; $p = .063$). However, there was a significant relationship in the control group between WTAR scores and AUC (r[51] = −0.31; $p = .03$).

To control for the effect of intelligence on discounting performance a between-groups ANCOVA was conducted. This used the WTAR estimate of IQ for the control group, and WAIS III for the TBI group. The between-subject variable was group, with AUC as the dependent measure. There was a significant between-group difference in the level of discounting measured by the AUC. The analysis revealed a significant main effect for group after adjusting for the influence of IQ (F[1,99] = 16.82; $p = .001$; $\eta_p^2 = 0.145$), indicating that the TBI group discounted at a steeper rate across the time delays compared to controls.

Impulsivity

The means and standard deviations for total scores on the Barratt Impulsiveness Scale (BIS II) and across the three subcomponents of the BIS II are presented in Table 2.

Results revealed significant group differences (BIS II total score: $t(100) = 6.09$, $p = .001$, SE 2.25; non-planning: $t(100) = 4.85$, $p = .000$, SE 1.09; motor impulsivity: $t(100) = 4.18$, $p = .001$, SE .83; attention: $t(100) = 6.14$, $p = .001$, SE .80), suggesting that the TBI group were significantly more impulsive than the age-matched control group.

To determine whether there was a relationship between the discounting task and impulsivity as measured by the BIS II a series of correlations were conducted between AUC, total BIS II scores, and attention, motor and non-planning subscores. After Bonferroni correction, the area under the curve for the TBI group was significantly related to the total BIS II score (r[51] = −0.37; $p = .008$), and the attention subscale

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Table 2. Mean and standard deviations scores for the TBI and Control groups for Total BIS II and the three BIS II subscales

	TBI		Control	
	M	*SD*	*M*	*SD*
Total BIS II	69.67	11.85	55.98	10.83
Attention	18.59	3.93	13.67	4.17
Motor	24.78	4.76	21.31	3.55
Non-planning	26.29	5.71	21.00	5.31

($r[51] = -.45$; $p = .001$). There was no relationship between AUC and motor ($r[51] = -.31$; $p = .026$) or non-planning ($r[51] = -.19$; $p = .19$) subscales in the TBI group. In the control group, AUC scores were significantly related to the total BIS II score ($r[51] = -.45$; $p = .001$), and subscales non-planning ($r[51] = -.39$; $p = .005$) and motor ($r[51] = -.41$; $p = .003$) but not attention ($r[51] = -.33$; $p = .02$).

Neuropsychological Measures

After Bonferroni correction (adjusted p level = .002) none of the measures correlated significantly with AUC (see Table 3 for a summary of means and standard deviations across all neuropsychological measures).

Ratings by Relatives

DEX-O ratings were available for 49 patients in the TBI group ($M = 48.33$; $SD = 14.35$). A correlation was conducted between DEX-O scores and the temporal discounting task to determine whether relative's ratings of executive dysfunction related to temporal discounting performance. No significant correlation was found ($r[49] = 0.14$; $p = .38$).

AUC and Depression

To determine whether there was a relationship between mood and temporal discounting for the TBI participants a correlational analysis was conducted between Beck Depression Inventory II (BDI II) Scores and AUC. The analysis revealed no significant relationship between BDI and AUC scores $r[51] = -0.04$; $p = 0.77$.

DISCUSSION

The aim of this study was to extend the exploratory work of McHugh and Wood (2008) by examining how well temporal discounting performance after TBI reflected poor decision making and whether this was related to intellectual factors, impulsivity, poor memory, or executive dysfunction as measured by clinical tests or on the basis of ratings made by relatives. We also included a measure of depression to examine mood-related influences on performance.

As in the original pilot study, we found that even though both groups discounted the LLR more as temporal factors increased, the rate of temporal discounting was significantly higher for TBI participants compared to healthy controls matched for age and gender. Intelligence seemed to mediate responding in the control group because their WTAR estimated IQ levels were related to AUC scores. However, no such relationship was found for the TBI group, where post injury intellectual level was measured more stringently using the WAIS III. This seems to conform to the "frontal paradox" (Walsh, 1985) which points to individuals with predominantly frontal injury after TBI being unable to use intelligence to guide their actions, or understand and respond to social and environmental cues (Cicerone & Tanenbaum, 1997).

A relationship was found between self-ratings of impulsivity and discounting performance. The performance of both TBI and control groups was significantly related to total BIS II scores. In the TBI group, this mainly reflected poor scores on the attention subscale because there was no relationship with subscales measuring motor and non-planning aspects of impulsivity. In contrast, temporal discounting

Table 3. Means and standard deviations for TBI Participants on neuropsychological measures

Measure	Mean	Standard deviation
WAIS III		
Vocabulary	8.14	2.51
Similarities	8.02	2.27
Arithmetic	8.67	2.90
Digit span	9.02	2.68
Comprehension	8.08	2.77
Picture Completion	9.30	3.35
Digit symbol	7.26	2.78
Block design	8.69	2.40
Matrix reasoning	9.24	3.01
Picture arrangement	8.43	1.73
Symbol search	8.55	3.15
WMS III		
Logical memory 1	8.18	3.20
Logical memory 2	7.62	3.83
Faces 1	7.94	2.47
Faces 2	8.62	2.68
Verbal paired associates 1	8.35	3.25
Verbal paired associates 2	8.08	3.13
Family pictures 1	5.50	2.84
Family pictures 2	5.49	3.16
Letter number sequencing	8.29	3.21
Spatial span	9.57	2.93
Auditory Recognition Delayed	7.82	2.68
Hayling Test		
Hayley A	5.13	1.25
Hayley B	5.56	1.13
Hayley C	5.60	1.92
BADS		
Key search	2.89	1.22
Zoo map	2.36	0.99
Rule shift	3.08	1.30
Action programme	3.64	0.83
Temporal judgement	1.86	0.93
Modified six elements	3.2	0.99

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performance in the control group was related to motor and non-planning components of impulsivity, but not attention.

As expected, there were no significant relationships between AUC and memory functions, as measured by the WMS III. Also, contrary to the findings of Willner et al. (2010), who examined temporal discounting in adults with developmental disabilities, we did not find a relationship with executive ability, even though we used a selection of executive tests that are currently used (at least in the UK) as ecological measures of executive function. We were surprised to find an absence of any relationship between discounting performance and relatives' ratings of executive dysfunction on the DEX-O. This is probably explained by the generalized nature of ratings on the DEX-O. By comparison, temporal discounting measures a specific aspect of judgment and decision making, largely related to financial decision making. Finally, there was no relationship between emotion (measured by low mood on the BDI) and discounting performance. The temporal discounting procedure therefore seems to offer something new in the assessment of decision making after TBI, particularly the ability to calculate relative monetary values when temporal factors are involved.

The study was not without limitations. Patients were referred because they exhibited a broad range of executive-type problems. Therefore, while they formed a clinically relevant sample, they could also be regarded as a biased sample in respect of measuring discounting performance. Although all members of the patient group had suffered head trauma, associated with diffuse patterns of injury predominantly implicating prefrontal structures, the computed tomography and MRI scans produced mixed results with regard to the primary loci of injury, which could have implications for discounting performance. Also, only a relatively small selection of executive tests was used. It is possible that other executive tests may have related more closely to performance on the temporal discounting task. However, we used tests that were designed to have ecological validity and were therefore considered most appropriate. An additional limitation was the self-report nature of the impulsivity questionnaire compared to observer ratings on the DEX. We acknowledge that self-report measures may be influenced by a lack of self-awareness and biased perception but, unlike the DEX-O, the BIS II does not have an observer rating option. In future research, it would be advisable to obtain rating scale observations from significant others in combination with recently developed rating scales for impulsive behavior after TBI (Oddy, Cattran, & Wood, 2008). Finally, trying to match levels of intelligence between the patient and control groups using different measures (WAIS III and WTAR) may be a crude comparison. However, the WTAR has been normed against the WAIS III and therefore can be assumed to be a relevant comparator and one which is more easily administered to a control group than tests from the WAIS III.

Allowing for these limitations, and the need for further research to provide more extensive normative data, temporal discounting has the potential to offer a useful paradigm to examine decision-making abilities in relation to monetary reward after TBI. The paradigm could therefore be a useful addition to existing neuropsychological test batteries when aspects of financial decision making need to be assessed, such as when trying to determine a person's capacity to manage their affairs after head trauma. Discounting performance seems to be reasonably independent of intellectual ability per se and may provide more reliable information about decision making abilities than standard neuropsychological tests.

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REFERENCES

Ainslie, G. (2001). *Breakdown of will*. Cambridge: Cambridge University Press.

Barratt, E.S. (1994). Impulsiveness and aggression. In J. Monahan & H.J. Steadman (Eds.), *Violence and mental disorder: Developments in risk assessment* (pp. 61–79). Chicago, IL: University of Chicago Press.

Beck, A.T., Brown, G., & Steer, R.A. (1996). *Beck Depression Inventory II Manuel*. San Antonio, TX: The Psychological Corporation.

Bechara, A., Damasio, H., & Damasio, A.R. (2003). Role of the amygdala in decision-making. *Annals of the New York Academy of Sciences*, *985*, 356–369.

Bechara, A., Damasio, A.R., Damasio, H., & Anderson, S.W. (1994). Insensitivity to future consequences following damage to prefrontal cortex. *Cognition*, *50*, 7–15.

Bechara, A., Damasio, H., Damasio, A.R., & Lee, G.P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *Journal of Neuroscience*, *19*, 5473–5481.

Bechara, A., Tranel, D., & Damasio, H. (2000). Characterisation of the decision making deficit of patients with ventromedial prefrontal cortex lesions. *Brain*, *123*(11), 2189–2202.

Buelow, M.T., & Suhr, J.A. (2009). Construct validity of the Iowa Gambling Task. *Neuropsychological Review*, *19*(1), 102–114.

Burgess, P.W., & Shallice, T. (1997). *The Hayling and Brixton Tests*. Bury St. Edmunds, UK: Thames Valley Test Company.

Carpenter, P., Just, M.A., & Reichle, E. (2000). Working memory and executive function: Evidence from neuroimaging. *Current Opinion in Neurobiology*, *10*, 195–199.

Christ, S.E., White, D.A., Brunstrom, J.E., & Abrams, R.A. (2003). Inhibitory control following perinatal brain injury. *Neuropsychology*, *17*, 171–178.

Cicerone, K.D., & Tanenbaum, L.N. (1997). Disturbance of social cognition after traumatic orbitofrontal injury. *Archives of Clinical Neuropsychology*, *12*, 175–188.

Crean, J.P., de Wit, H., & Richards, J.B. (2000). Reward discounting as a measure of impulsive behavior in a psychiatric outpatient population. *Experimental & Clinical Psychopharmacology*, *8*, 155–162.

Critchfield, T.S., & Kollins, S.H. (2001). Temporal discounting: Basic research and the analysis of socially important behavior. *Journal of Applied Behavior Analysis*, *34*, 101–122.

Drevets, W.C., & Raichie, M.E. (1998). Reciprocal suppression of regional blood flow during emotional verses higher cognitive processes: implications for interaction between cognition and emotion. *Cognition & Emotion*, *12*(3), 353–385.

Duncan, J., Burgess, P., & Emslie, H. (1995). Fluid intelligence after frontal lobe lesions, *33*(3), 261–268.

Green, L., & Myerson, J. (1993). Alternative frameworks for the analysis of self control. *Behavior and Philosophy*, *21*(2), 37–47.

Greve, K., Sherwin, E., Stanford, M., Mathias, C., Love, J., & Ramzinski, P. (2001). Personality and neurocognitive correlates of impulsive aggression in long-term survivors of severe traumatic brain injury. *Brain Injury*, *15*, 255–262.

Klapproth, F. (2011). Stable and variable characteristics of the time perspective in humans. *KronoScope*, *11*(1-2), 41–59.

Johnson, M.W., & Bickel, W.K. (2002). Within-subject comparisons of real and hypothetical monetary rewards in delayed discounting. *Journal of Experimental Analysis of Behavior*, *77*, 129–146.

Marsh, D.M., Dougherty, D.M., Mathias, C.W., Moeller, F.G., & Hicks, L.R. (2002). Comparisons of women with high and low trait impulsivity using behavioral models of response-disinhibition and reward-choice. *Personality and Individual Differences*, *33*, 1291–1310.

McAllister, T.W. (2007). Neuropsychiatric aspects of TBI. In N.D. Zazler, D.I. Katz, & R.D. Zafonte, (Eds). *Brain injury medicine* (pp. 835–865). New York: Demos Medical Publishing.

McHugh, L., & Wood, R.Ll. (2008). Using a temporal discounting paradigm to measure decision making and impulsivity following traumatic brain injury: A pilot study. *Brain Injury*, *22*(9), 715–721.

McMillan, T.M., Jongen, E.L., & Greenwood, R.J. (1996). Assessment of post-traumatic amnesia after severe closed head injury: Retrospective or prospective? *Journal of Neurology, Neurosurgery, and Psychiatry*, *60*, 422–427.

Miller, L.A. (1992). Impulsivity, risk taking and the ability to synthesize fragmented information after frontal lobectomy. *Neuropsychologia*, *30*, 69–79.

Myerson, J., & Green, L. (1995). Discounting of delayed rewards: Models of individual choice. *Journal of the Experimental Analysis Behavior*, *64*, 263–276.

Oddy, M., Cattran, C., & Wood, R.Ll. (2008). The development of a measure of motivational changes following acquired brain injury. *Journal of Clinical and Experimental Neuropsychology*, *30*(5), 568–575.

Patton, J.H., Stanford, M.S., & Barratt, E.S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology*, *51*, 768–774.

Pfister, H.R., & Bohm, G. (2008). The multiplicity of emotions: A framework of emotional functions in decision making. *Judgment and Decision Making*, *3*(1), 5–17.

Rachlin, H., & Green, L. (1972). Commitment, choice, and self control. *J Experimental Analysis of Behaviour*, *17*(1), 15–22.

Reed, D., & Martens, B. (2011). Temporal discounting predicts student responsiveness to exchange delays in a classroom token system. *Journal of Applied Behavior Analysis*, *44*, 1–18.

Richards, J.B., Zhang, L., Mitchell, S.H., & De Wit, H. (1999). Delay or probability discounting in a model of impulsive behavior: Effect of alcohol. *Journal of the Experimental Analysis of Behavior*, *71*, 121–143.

Shamosh, N.A., DeYoung, C.G., Green, A.E., Reis, D.L., Johnson, M.R., Conway, A.R.A., … Gray, J.R. (2008). Individual differences in delay discounting: Relation to intelligence, working memory, and anterior prefrontal cortex. *Psychological Science*, *19*(9), 904–911.

Stanford, M.S., Mathias, C.W., Dougherty, D.M., Lake, S.L., Anderson, N.E., & Patton, J.H. (2009). Fifty years of the Barratt Impulsiveness Scale: An update and review. *Personality and Individual Differences*, *47*, 385–395.

Teasdale, G., & Jennett, B. (1974). Assessment of coma and impaired consciousness. *A practical scale. Lancet*, *2*, 81–84.

The Psychological Corporation. (2001). *Wechsler Test of Adult Reading*. San Antonio, TX: Harcourt Assessment.

Walsh, K.W. (1985). *Understanding brain damage: A primer of neuropsychological evaluation*. London: Churchill Livingstone.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale—3rd Edition (WAIS-3)*. San Antonio, TX: Harcourt Assessment.

Willner, P., Bailey, R., Parry, R., & Dymond, S. (2010). Performance in temporal discounting tasks by people with intellectual disabilities reveals difficulties in decision-making and impulse control. *American Journal on Intellectual and Developmental Disabilities*, *115*, 157–171.

Wilson, B.A., Evans, J.J., Alderman, N., Burgess, P.W., & Emslie, H. (1997). Behavioural assessment of the dysexecutive syndrome. *Neuropsychological Rehabilitation*, *5*, 662–676.

Yuen, K.S.L., & Lee, T.M.C. (2003). Could mood affect risk taking decisions? *Journal Affective Disorders*, *75*, 11–18.

Zeelenberg, M., Nelissen, R.M.A., Breugelmans, S.M., & Pieters, R. (2008). On emotion specificity in decision making: Why feeling is for doing. *Judgment and Decision Making*, *3*, 18–27.