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IMPULSIVITY, SELF-CONTROL, AND DELAY DISCOUNTING IN PERSONS WITH ACQUIRED BRAIN INJURY

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The present paper describes two studies in which participants with and without acquired brain injuries were compared on a temporal discounting task involving various hypothetical amounts of money available at varying delay values. During Experiment 1, both groups of participants were presented with choices between amounts of money ranging from 1 to 1000 US dollars at delays from 1 week to 10 years. The results obtained from this procedure were consistent with previous models of temporal delay discounting for control group participants, yet not for the majority of the participants with acquired brain injuries. During Experiment 2, adjustments in hypothetical amounts and delays were made whereby the amounts of money ranged from 1 to 20 US dollars at delays from 1 day to 1 year. These manipulations yielded data generally consistent with temporal delay discounting models previously reported in the published literature. The utility of using delay discounting procedures as a means of assessing impulsivity in persons with acquired brain injuries is presented. Copyright © 2005 John Wiley & Sons, Ltd.

INTRODUCTION

The newly emerging behavioral repertoire of a person who has acquired a brain injury has been repeatedly termed 'impulsive' or lacking in 'self-control' (see, e.g., Brain Injury Society of America, 2004). However, the term 'impulsive' often lacks an objective operational definition. For example, impulsive behavior exhibited by persons with brain injury may take the form of stealing, sexual aggression, pyromania, or impulsive shopping (Anderson, Parmenter, & Mok, 2002; Andrews, Rose, & Johnson, 1998). Behaviorally, the impulsivity that is often exhibited by persons with brain injury might be conceptualized as the selecting of a sooner smaller

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reinforcer over a larger delayed reinforcer (Dixon & Falcomata, 2004; Dixon, Horner, & Guercio, 2003). For example, if a person with a brain injury is presented with the choice of engaging in physical therapy right now and that activity might produce a long-term delayed reinforcer of greater rehabilitation, versus engaging in a problem behavior and escaping the demands, oftentimes the consequences of behavior are too delayed to understand and this limitation may be exacerbated by the brain injury itself.

A first step that care providers might wish to take in the care for persons with brain injury is to conduct an assessment of impulsivity to determine the specific direction that therapy should take. Unfortunately, a valid and reliable assessment device that can detect and measure impulsivity in the brain injury population is lacking in the published literature. This is partially if not fully due to a clear understanding and consensus of what defines impulsivity for a person with brain injury. Therefore, it may be advantageous for care providers to explore innovative means of assessment for determining degrees of impulsivity, and the failure to understand the consequences of delayed actions. A procedure that has gained considerable attention in the experimental analysis of behavior is entitled 'delay discounting'.

Delay discounting is a behavior analytic approach to understanding how different people make choices between smaller rewards given immediately and larger rewards given after a delay, to assess the degree of impulsivity or self-control. In research studies, these rewards are often presented in the form of hypothetical monetary amounts (Rachlin, Raineri, & Cross, 1991). As a function of a delayed interval of time, the subjective value of each of the delayed monetary reward decreases. In other words, as the amount of time to a given reward increases, the subjective value of the reward decreases, and the more likely the individual is to choose the smaller/immediate reward. The delay interval of the larger/delayed reinforcer is then extended out in time to determine whether the subject discounts the value of the delayed reward at a higher rate as the delay to the larger reward is increased in time. The use of hypothetical rewards, which tend to be more practical for research, has been compared with actual monetary rewards when using a delay discounting procedure and the two consequences appear functionally similar (see, e.g., Bickel, Odum, & Madden, 1999; Madden, Begotka, Raiff, & Kastern, 2003; Madden, Bickel, & Jacobs, 1999; Mitchell, 1999; Petry & Casarella, 1999).

Mazur's (1987) equation is often used in to determine the quantitative degree temporal of discounting a research participant may exhibit:

$$V = A/(1 + kD)$$

In this equation, V is the subjective value of the delayed reward, which is the indifference point where the delayed reward is equally as valuable as the immediate reward. *A* is the nominal amount of delayed reward, or the actual monetary amount. *k* is a free parameter that describes the sensitivity to change in delay. *D* is the length of the delay to the reinforcer. As the *k* value increases, *V* decreases as a function of *D*. In other words, as the value of *k* increases, the discounted value of the hypothetical reward decreases more rapidly as a function of the delay in time. The indifference points that result from the equation are then put into a hyperbolic model that permits the examination of preference reversals in subjective choice making. This equation has been used in studies where participants discounted hypothetical amounts of drugs (e.g. Madden, Bickel, & Jacobs, 1999) and money (e.g. Kirby, Petry, & Bickel, 1999; Myerson & Green, 1995). It has been shown in previous studies that individuals with substance abuse problems or a co-morbidity of substance abuse and gambling will have larger *k* values (Madden et al., 1999; Madden, Petry, Badger, & Bickel, 1997; Petry & Casarella, 1999). Recently, these claims have also held true for pathological gamblers compared with matched non-gambling controls (Dixon, Marley, & Jacobs, 2003).

Therefore, the purpose of the present study was to determine whether a hypothetical money choice task would produce similar degrees of delay discounting from persons with brain injury that have been observed with other clinical populations that are often described as impulsive. First we compared a group of persons with brain injuries with matched control participants on a standard hypothetical choice money task. Second, we reduced the hypothetical amounts of money and delay values so that they more accurately resembled the choices that persons with acquired brain injury that are living in a residential care facility may encounter.

EXPERIMENT 1 METHOD

Participants and Setting

Forty two subjects participated in this study. Nineteen individuals (16 men and 3 women, mean age = 30) with brain injury who resided at a residential treatment facility were recruited for participation. Twenty-three individuals (20 men and 3 women, mean age = 22) who reported no history of acquiring a brain injury during their lifetime were recruited from a large university's student center (student union) to serve as control group participants. Individual participant characteristics are displayed in Tables 1 and 2.

Consent to participate was obtained from all participants or their legal guardians, as was the case for many of the persons with brain injury. No compensation was provided for completion of the experimental task. Participants with brain injury completed the procedures in a quiet location in their residence that may have

Table 1. Demographic data including length of coma (LOC), time since injury (TSI), previous participation in Alcoholics or Narcotics Anonymous (AA/NA) and educational level (Ed.) for participants with acquired brain injuries who participated in Experiment 1.

Part. No.	*Age*	*Gender*	*Location of injury*	*LOC*	*Severity*	*TSI*	*Cause*	*AA*	*NA*	*Ed.*
503	29	m	CVAs and skull fracture	<30	mild	12	bike accident	y	y	12
505	25	m	small epidural hematoma and depressed skull fracture	>24	severe	7	motor vehicle accident	y	n	12
509	20	m	small intraparenchymal hemormages in the right frontotemporal area	>24	severe	2	motor vehicle accident	n	n	12
511	27	m	epidural bleed evacuation surgery and MVA later	<30	mild	15	fall	n	n	16
554	28	m	intraventricular hemorrhage hematoma	<30	severe	2	motor vehicle accident	n	n	13
553	44	m	rightsubdural with a mass effect shift	<24	severe	2	assault	n	n	14
555	28	m	acquired brain injury—anoxic encephalopathy and cardiac arrest	unknown	unknown	3	drug overdose	n	y	10
515	22	m	multiple contusions across many areas of the brain	>24	severe	6	jumped out of a car	n	n	12
514	37	m	result of infarct post bilateral valve replacement surgery	>24	severe	7	medical procedure	n	n	14
501	39	m	traumatic brain injury—not specified	>24	severe	16	motor vehicle accident	y	y	9
508	37	m	truamatic brain injury with multiple spinal fractures	unknown	unknown	13	motor vehicle accident	n	n	12
510	29	m	diffuse edema with blood in the 3rd ventricle	>24	severe	10	motor vehicle accident	y	n	10
552	21	m	traumatic brain injury—not specified	<30	severe	5	motor vehicle accident	n	n	12
513	26	m	right frontal hematoma, right subdural meatoma and generalized edema	>24	severe	13	motor vehicle accident	n	n	12
502	20	m	traumatic brain injury—not specified	<30	mild	16	motor vehicle accident	n	n	12
506	55	f	ruptured communicating artery aneurysm and subsequent intracranial bleed	<30	mild	2	aneurysm	n	n	14
550	39	f	basilar skull fracture and cerebral edema	<24	severe	24	motor vehicle accident	n	y	12
551	21	f	skull fracture; severe concussion with intracranial pressure; intercerebellar hemorrhages	<30	severe	19	motor vehicle accident	n	n	11
504	20	m	traumatic brain injury—not specified	unknown	unknown	5	assault	n	n	9

Table 2. Demographic data including previous participation in Alcoholics or Narcotics Anonymous (AA/NA) and educational level (Ed.) for control participants without acquired brain injuries who participated in Experiment 1.

Part. No.	*Age*	*Gender*	*Location of injury*	*LOC*	*Severity*	*TSI*	*Cause*	*AA*	*NA*	*Ed.*
600	21	f						n	n	15
603	28	f						n	n	16
605	25	m						n	n	18
608	21	m						n	n	13
610	26	m						n	n	16
803	21	m						n	n	14
804	18	f						n	n	13
805	23	m						n	n	15
807	20	m						n	n	12
809	19	m						n	n	12
810	18	m						n	n	12
811	25	m						n	n	15
607	19	f						n	n	12
800	24	m						n	n	18
808	21	m						n	n	14
806	21	f						n	n	14
606	19	m						n	n	13
611	20	m						n	n	13
802	20	m						n	n	13
609	21	f						n	n	14
602	25	m						n	n	17
801	25	m						n	n	17
604	21	f						n	n	15

included their bedroom, a kitchen table, the living room, or outside on a patio. Control group participants completed the procedures at a table within the common dining area of the university's student center.

Materials

All experimental procedures were completed on Windows-based laptop computers that were programmed in Visual Basic.NET (see Dixon & MacLin, 2003 for utilizing Visual Basic.NET for behavior analytic research). Hypothetical monetary amounts, delays, and instructions were displayed on the computer screen. Instructions consisted of the following:

'Which amount of money would you like to have?'

Below this question were two amounts of money, one available immediately, and the other available after a delayed period of time. The delayed amount of money was always $1000 and was located on the right-hand side of the computer display. Positioned above this amount of money was the actual delay time displayed in a large font. Delays were 1 week, 2 weeks, 1 month, 6 months, 1 year, 3 years, and 10 years. The immediate amounts of money and the word 'NOW' were located on the left-hand side of the computer display. The immediate amounts varied throughout successive choices, but consisted of the following values: $1000, $990, $960, $920, $850, $800, $750, $700, $650, $600, $550, $500, $450, $400, $350, $300, $250, $200, $150, $100, $80, $60, $40, $20, $10, $5 and $1.

Procedure

One session lasting from 15 to 60 min was conducted with all participants. Before initiation of the session, all participants read over an informed consent document. For those participants with brain injury who were not their own guardians, approval was obtained from their guardians prior to session initiation. Additionally, these participants were asked whether they would like to work on the computer and make some choices about various amounts of 'pretend' money.

All participants were also informed that all the rewards that would be displayed on the computer screen were hypothetical and that they would not receive any of the amounts they chose. They were told that there were no wrong answers and to choose the option they wanted to have. The following instructions were also verbally presented to all participants:

> This computer program will ask you to make some choices about money. You will not get the money that you choose, but I want you to make your choices as though you were really going to get the money. The amount of money on the left side of the computer screen shows the amount of money that you can have right now. The money on the right side of the computer screen shows the amount of money that you can have after waiting different amounts of time. After you make your choice, another set of money amounts will be presented. This process will continue until the computer program is done.

After answering any additional questions about the experimental procedure, the experimenter initiated the computer program. The initial choice trial was between $1000 available immediately or $1000 available after 1 week. After making the choice between these two alternatives, the amount of money on the left-hand side of the computer screen (amount available immediately) decreased in value to $990 while the amount of money on the right-hand side of the computer screen (amount available after 1 week) remained at $1000. The process of decreasing the immediate amount of money in the choice task continued until the immediate amount of money equaled $1. After the choice between $1 available right now or $1000 available after

1 week, the amounts of immediate money began to increase again from \$1 to \$5 to \$10 and so on until the immediate amount of money equaled \$1000. After all choices between the descending amounts of immediate money (\$1000 down to \$1) and ascending amounts of immediate money (\$1 up to \$1000), the delay to access the delayed amount of money was increased. Now, instead of the delayed amount of money being available after 1 week, it was available after 2 months. The sequence of choices between descending and ascending amounts of immediate money were repeated with this new delay period. Delays were increased in this fashion until choices had been made at delays equal to 10 years. All control participants used the computer mouse and made their own selections by placing the pointer over their preferred choice and clicking the mouse button. Due to a wide variety of physical disabilities such as tremors and partial paralysis as well as varying knowledge about using a laptop mouse pointer, all participants with brain injury were asked to speak aloud their choice between the two alternatives and the experimenter selected that option by moving and clicking the mouse for the participant.

For each participant a 'switch point' or 'indifference point' was calculated for each delay period by taking the average of the last immediate amount that was selected on the ascending sequence and the first immediate amount selected on the descending sequence. The discounting equation was fit to individual and group data using Microsoft Excel's Solver Add-In. Degrees of discounting (k values) were calculated with delays that were measured in weeks.

EXPERIMENT 1 RESULTS

Tables 3 and 4 show delay discounting data for the participants with brain injury and control participants, respectively. The columns labeled 'Error' in Tables 3 and 4 show the number of times each participant preferred the delayed \$1000.00 to the immediate \$1000.00. Although these choices occurred with participants from both groups, these choices occurred more frequently in the participants with brain injury. Twelve of 19 participants with brain injury and 11 of 23 control participants chose the delayed \$1000.00 over the immediate \$1000.00 at least once. The mean number of choices was 2.79 for participants with brain injury and was 1.09 for control participants. The difference in the means from the two groups was statistically significant (two tailed t-test, $t(40) = 2.21$, $p = 0.033$).

Ideally, we should have obtained only two indifference points per delay for each participant—one from the ascending sequence of immediate reward values and one from the descending sequence of immediate reward values. Often, however, participants would vacillate back and forth between the immediate and delayed rewards, yielding more than one indifference point for the condition. The total

Table 3. Indifference points at each delay, derived *k* values, proportion of variance accounted for by the hyperbolic model (R^2), and areas under the curve (AUCs) for participants with acquired brain injuries (ABI) completing Experiment 1.

	Delay (weeks)											
ABI	*1*	*2*	*4*	*26*	*52*	*156*	*520*	*No. IP*	*Error*	*k*	R^2	*AUC*
503	940	940	885	885	885	5	5	14	0	0.0128	0.80	0.181 375
505	775	525	475	475	225	175	50	14	0	0.2196	0.51	0.160 986
509	825	857.5	600	425	132.5	5	5	14	0	0.1053	0.95	0.058 596
511	985	995	995	995	995	995	775	14	0	0.0005	0.87	0.917 986
554	912.5	775	175	107.5	50	30	5	14	0	0.3162	0.86	0.035 332
553	997.5	957.5	135	282.5	5	5	5	15	1	0.2278	0.77	0.026 296
555	995	995	995	995	995	995	997.5	14	0			
515	995	995	997.5	995	995	995	997.5	14	1			
514	1000	1000	5	5	1000	1000	1000	14	9			
501	812.5	1000	805	1000	475	985	800	15	4			
508	253.75	767.5	685	942.5	515	862.5	560	16	6			
510	967.5	1000	953.75	675	792.5	425	606.25	21	5			
552	1000	501.25	458.75	502.5	638.75	501.25	5	23	8			
513	487.5	675	387.5	525	985	475	501.25	27	3			
502	450	537.5	85	5	5	1000	5	28	3			
506	1000	852.5	855	650	662.5	612.5	5	37	3			
550	300	550	656.25	500	530	650	400	48	6			
551	336.25	366.25	462.5	528.75	127.5	135	597.5	57	0			
504	1000	952.5	437.5	350	500	312.5	537.5	73	4			

number of indifference points (No. IP) obtained for each participant is also included in the tables. Values greater than 14 (i.e. points from two sequences at each of the seven delays) indicate the degree to which the participant vacillated between the options. The participants with brain injury were much more prone to vacillation than the control participants. Eleven of 19 participants with brain injury had more than 14 indifference points, whereas only 7 of 23 control participants exceeded 14 switches. The mean number of indifference points was 24.84 for participants with brain injury and 14.78 for control participants. The difference in the means from the two groups was statistically significant (two tailed *t*-test, $t(40) = 2.42$, $p = 0.020$).

The indifference points at each delay are shown in Tables 3 and 4 for the participants with brain injury and control participants, respectively. The data shown are the averages of the medians of the indifference points obtained from the ascending and descending conditions at each delay. If a participant chose the delayed \$1000.00 over the immediate \$1000.00, then an indifference point of \$1000.00 was included in the calculation of the median for the condition. If a participant preferred \$10.00 immediately to \$1000.00 after a delay, the indifference point was set to \$5.00.

Table 4. Indifference points at each delay, derived *k* values, proportion of variance accounted for by the hyperbolic model (R^2), and areas under the curve (AUCs) for participants without acquired brain injuries (controls) completing Experiment 1.

	Delay (weeks)											
Control	*1*	*2*	*4*	*26*	*52*	*156*	*520*	*No. IP*	*Error*	*k*	R^2	*AUC*
600	885	825	775	675	500	250	562.5	14	0	0.0158	0.07	0.425 692
603	912.5	912.5	912.5	930	825	750	400	14	0	0.0027	0.89	0.649 870
605	995	975	940	885	825	700	675	14	0	0.0015	0.55	0.722 490
608	300	600	500	5	5	5	5	14	0	0.6074	0.58	0.019 188
610	912.5	855	675	425	200	125	10	14	0	0.0748	0.98	0.124 668
803	830	550	475	225	232.5	70	5	14	0	0.2600	0.90	0.087 570
804	912.5	912.5	912.5	830	912.5	755	505	14	0	0.0021	0.74	0.695 276
805	995	975	940	855	885	775	450	14	0	0.0023	0.94	0.683 663
807	967.5	700	650	300	150	15	5	14	0	0.1262	0.98	0.060 457
809	995	995	995	860	550	300	5	14	0	0.0137	0.97	0.273 471
810	975	885	800	725	475	30	5	14	0	0.0263	0.93	0.131 625
811	940	940	885	885	825	625	500	14	0	0.0029	0.80	0.626 067
607	997.5	995	995	885	830	750	800	14	1	0.0008	0.17	0.790 649
800	940	987.5	855	550	425	175	5	14	1	0.0305	0.99	0.183 945
808	995	995	997.5	885	775	775	525	14	1	0.0021	0.87	0.698 772
806	755	475	325	200	515	102.5	40	15	1	0.3853	0.35	0.145 197
606	997.5	942.5	878.75	200	90	400	5	15	3	0.0736	0.85	0.227 350
611	995	997.5	997.5	743.75	650	600	5	15	3	0.0088	0.91	0.415 764
802	995	1000	957.5	1000	942.5	600	225	14	5			
609	1000	855	225	5	995	995	997.5	15	2			
602	700	650	475	556.25	450	275	300	16	1			
801	726.25	940	942.5	1000	926.25	970	970	16	6			
604	512.5	725	450	475	5	5	5	24	1			

To be consistent with delay discounting, indifference points should decrease across successive delays. That is, the subjective value of the delayed reward should be a continuously decreasing function of delay. The data from many participants departed from this pattern, however. Such departures are not uncommon in the delay discounting literature, thus it is necessary to adopt some criteria for identifying which data sets are at least broadly consistent with delay discounting. In the present study, a participant's data were considered to be consistent with delay discounting, broadly construed, if the indifference points decreased at least twice across successive delay values and did not increase more than once. At the 1 week delay condition, indifference points of less than $1000.00 were counted as decreases. These criteria yielded six data sets from the participants with brain injury and 18 data sets from the control participants that were consistent with delay discounting.

Equation (1) was fit to the indifference points for those participants whose data met the above inclusion criteria. The derived *k* parameters and the percent variance accounted for (R^2) are reported in Tables 3 and 4 for the participants with brain injury and controls, respectively. Generally, Equation (1) provided a good description of the delay discounting data from these participants. The mean proportion of variance accounted for was 0.87 (range 0.51–0.95) for the participants with brain injury and 0.75 (range 0.07–0.99) for the control participants. Across both groups, the proportion of variance accounted for by Equation (1) exceeded 0.51 for 21 of 24 participants. A Wilcoxon rank-sum test (Huck, 2000) was performed to determine whether the ranks of the degrees of discounting (*k*) were significantly higher for the participants with brain injury than for the controls. A nonparametric test was used because the distributions of the parameter estimates are not normal. The difference in the sums of ranks of the discounting parameters (*k*) between the groups was not statistically significant ($W_s = 61$, $n_1 = 6$, $n_2 = 18$, $p > 0.10$).

The area under the indifference curve (AUC) is also provided in Tables 3 and 4 for each participant whose data were consistent with delay discounting. The area under the indifference curve provides another measure of delay discounting (for details see Myerson, Green, & Warusawitharana, 2001). Unlike the hyperbolic model, the area under the curve is theoretically neutral with respect to the form of the indifference curve, thus accommodating a greater range of data than the hyperbolic model. The area under the curve can range from 0.0 (steepest discounting) to 1.0 (no discounting). The means of the areas under the curve were 0.2301 and 0.3868 for the participants with brain injury and controls, respectively. Again, the difference in the means from the two groups was not statistically significant (one tailed *t*-test, $t(26) = 0.41$, $p = 0.34$).

Figure 1 shows aggregate discounting curves for participants whose data were consistent with delay discounting from both groups. The data points show the

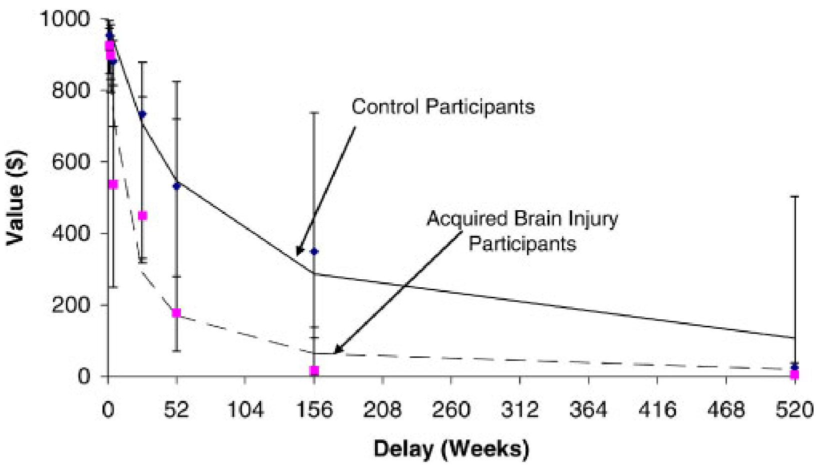

Figure 1. Hyperbolic discounting functions for participants in Experiment 1.

medians of the individual indifference points at each delay and the error bars show the interquartile ranges of the indifference points. Equation (1) was fit to the median indifference points for both groups and provided a good description of the aggregate delay discounting data. The proportions of variance accounted for by Equation (1) were 0.93 and 0.98 for participants with brain injury and controls, respectively. The dashed reference line in Figure 1 shows the best fit line for participants with brain injury and the solid reference line shows the best fit line for control participants. The derived k value for the aggregate data was higher for participants with brain injury ($k = 0.0932$) than for controls ($k = 0.0159$). Also, the area under the aggregate curve was smaller for participants with brain injury (AUC = 0.1098) than for controls (AUC = 0.3446). A paired t-test was conducted on the medians of the indifference points from the two groups and the differences were statistically significant ($t(6) = 3.78$, $p < 0.01$).

EXPERIMENT 1 DISCUSSION

The results from Experiment 1 suggest that when comparing the temporal discounting data from participants with brain injury to control participants it appears that the participants with acquired brain injuries discounted the delayed rewards more often than the controls. In other words, the participants with brain injury selected sooner smaller amounts of money more often than controls at the same delay values. These data support previous research on delay discounting when comparing pathological gamblers with matched controls (Dixon et al., 2003), and persons with substance abuse to matched controls (see, e.g., Madden et al., 1997, 1999). Our data extend the findings and utility of research conducted using temporal discounting tasks into the lives of persons with acquired brain injury—a population often considered to have problems with impulsivity (Anderson et al., 2002; Andrews et al., 1998). While we are not suggesting that impulsivity is simply a construct that can be accounted for with results from a temporal discounting task, it does appear that perhaps one characteristic of the broad construct of impulsivity is temporal discounting, and our experimental preparation was sensitive enough to illustrate this.

The data obtained in this experiment also differ from many previously published findings on temporal discounting. It may have been possible that our participants with brain injury did not understand the experimental task, or have the cognitive abilities to discriminate correctly between the amounts of money, the period of delays, or both. These limitations may have occurred because the amounts of money and delay periods that were used in our study, while used in previous research (Critchfield & Kollins, 2001; Madden et al., 1999), were not typical of the amounts of money or delays that a person with brain injury usually encounters. Many of our participants never received more than $20 in cash at one time for spending money, and such small amounts of money were often spent on items available immediately (e.g. cigarettes, soda, magazines, etc.). Furthermore, all the participants with brain injury resided at an intensive behavioral intervention program within the brain injury organization. Perhaps their severity of injuries and resulting behavior problems mitigated their ability to complete the temporal discounting task accurately. In attempts to answer some of our speculations regarding the discrepancies between the findings of Experiment 1 and previously published research on temporal discounting, we conducted a second experiment that reduced the amounts of hypothetical money, reduced the periods of time to gain access to the larger delayed amount of money, and incorporated a third group of participants with brain injury who did not emit challenging problem behaviors but were matched in terms of severity of injury, length of time since injury, and length of coma to the poorest performers of Experiment 1.

EXPERIMENT 2 METHOD

Participants

Nineteen subjects participated in the study. Six individuals from Experiment 1 whose data were the least consistent with delay discounting and contained the highest numbers of switches between immediate and delayed values were re-recruited and exposed to the contingencies of Experiment 2 (participants 502, 513, 506, 550, 551 and 504). Six experimentally naïve persons who suffered from an acquired brain injury and resided at the same residential treatment facility were also recruited for participation in Experiment 2 (five men and one woman, mean age = 41). This second group of persons with brain injury was selected from a division of the treatment facility that characteristically consisted of supervised apartments, or independent living arrangements. Individuals in this division characteristically rarely displayed any forms of problem behaviors (e.g. physical aggression, suicide attempts, verbal threats, etc.), which were very common and frequently occurred for our participants in Experiment 1. Seven experimentally naïve individuals (five men and two women, mean age = 26) who reported no history of acquiring a brain injury during their lifetime were recruited from the university's student center to serve as control group participants. Individual participant characteristics are displayed in Table 5. All settings remained identical to those of Experiment 1.

Materials

All experimental procedures were again completed on Windows-based laptop computers that were programmed in Visual Basic.NET. Hypothetical monetary

Table 5. Demographic data for all participants in Experiment 2.

Part. No.	Age	Gender	Location of injury	LOC	Severity	TSI	Cause	AA	NA	Ed.
Exp. 1										
502	20	m	traumatic brain injury —not specified	<30	mild	16	motor vehicle accident	n	n	12
513	26	m	right frontal hematoma, right subdural meatoma and generalized edema	>24	severe	13	motor vehicle accident	n	n	12
506	55	f	ruptured communicating artery aneurysm and subsequent intracranial bleed	<30	mild	2	aneurysm	n	n	14
550	39	f	basilar skull fracture and cerebral edema	<24	severe	24	motor vehicle accident	n	y	12
551	21	f	skull fracture; severe concussion with intracranial pressure; intercerebellar hemorrhages	<30	severe	19	motor vehicle accident	n	n	11
504	20	m	traumatic brain injury —not specified	unknown	unknown	5	assault	n	n	9
Naïve ABI										
RR001	34	m	brainstem contusion spastic hemispheres	>24	severe	17	motor vehicle accident	n	n	9
RR002	44	m	unknown	unknown	unknown	17	motor vehicle accident	n	n	16
RR005	54	m	unknown	unknown	unknown	18	motor vehicle accident	n	n	13
RR006	45	f	unknown	unknown	unknown	20	motor vehicle accident	n	n	11
RR004	33	m	depressed skull fracture, intra-cerebral contusions	>24	severe	17	motor vehicle accident	n	n	12
RR003	36	m	brainstem, right occipital lobe	>24	severe	3	hit by train	y	n	12
Controls										
C001	22	f						n	n	15
C002	23	m						n	n	16
C003	28	m						n	n	16
C004	37	f						n	n	23
C005	23	m						n	n	15
C006	27	m						n	n	15
C007	23	m						n	n	14

amounts, delays, and the same instructions as used during Experiment 1 were displayed on the computer screen. However, all amounts of money and delay values were altered from Experiment 1. The delayed amount of money was now always $20 and was located on the right-hand side of the computer display. Positioned above this amount of money was the actual delay time displayed in a large font. Delays were now 1 day, 3 days, 1 week, 1 months, 3 months, 6 months, and 1 year. The immediate amounts of money and the word 'NOW' were located on the left-hand side of the computer display. The immediate amounts varied throughout successive choices, but consisted of the following values: $20, $18, $16, $14, $12, $10, $8, $6, $4 and $2.

Procedure

All aspects of the experimental procedure were identical as conducted during Experiment 1. The new group of six participants with brain injury who did not regularly display problem behaviors (participant numbers 2000–2005) verbally stated their choices to the experimenter, as was the case with the re-recruited participants from Experiment 1. Control participants made their own choices using the computer mouse as occurred in Experiment 1.

To further determine each participant's ability to discriminate between choice options, a six-question survey was conducted. Questions such as: 'which is sooner: 3 days or 1 day?'; 'which is more: $1 or $10?' were given to each participant. Resulting mean test scores on this initial assessment were 97%, 92%, and 100% for re-run Experiment 1 participants, naïve participants with brain injury, and controls respectively.

EXPERIMENT 2 RESULTS

The performance of the six participants who also participated in Experiment 1 improved under the new conditions. Table 6 contains delay discounting data for the three groups of participants who completed Experiment 2. Comparing the data for these participants with brain injury shown in Table 6 to those shown in Table 3 indicates that the number of indifference points (No. IP) obtained decreased for all six participants. The mean number of indifference points fell from 45 in Experiment 1 to 21 in Experiment 2, a statistically significant decrease (paired t-test, $t(5) = 6.12$, $p < 0.002$). The mean number of instances in which these participants preferred the delayed $20.00 to an immediate $20.00 increased slightly in Experiment 2 ($M_{\text{Exp. 1}} = 3.17$, $M_{\text{Exp. 2}} = 4.67$), but the increase was not statistically significant (paired t-test, $t(5) = 1.29$, $p > 0.25$). The data from Participants 502 and 513 also met criteria for delay discounting, whereas they did not in Experiment 1.

Compared with the naïve participants with brain injury and the control participants, those from Experiment 1 were more prone to vacillating between the immediate and delayed outcome within a condition and were more likely to prefer the delayed $20.00 to the immediate $20.00. Analyses of variance revealed significant

Table 6. Indifference points at each delay, derived *k* values, proportion of variance accounted for by the hyperbolic model (R^2), and areas under the curve (AUCs) for participants re-run from Experiment 1 (Exp. 1), naïve participants with acquired brain injuries (Naive ABI) and control participants (Control) completing Experiment 2.

	Delay (days)											
	1	*3*	*7*	*14*	*30*	*90*	*365*	*No. IP*	*Error*	*k*	R^2	*AUC*
Exp. 1												
502	19.00	16.00	1.00	1.00	1.00	1.00	1.00	14.00	0	0.2815	0.79	0.001
513	19.00	19.00	14.25	13.00	17.25	10.00	10.00	18.00	3	0.0080	0.17	0.008
506	18.75	19.50	20.00	19.00	19.00	20.00	19.00	15.00	7			
550	9.50	10.00	12.00	12.50	7.25	7.00	5.00	20.00	1			
551	16.50	14.50	15.50	16.50	15.00	19.50	12.50	25.00	9			
504	15.25	13.00	14.50	17.00	11.75	5.50	5.00	34.00	8			
Naive ABI												
RR001	19.00	18.00	18.00	17.00	17.00	17.00	17.00	14.00	0	0.0007	−6.38	0.012
RR002	19.00	17.00	19.00	19.00	16.00	16.00	14.00	14.00	0	0.0016	−0.05	0.011
RR005	19.00	19.00	19.00	19.00	19.00	19.00	1.00	14.00	0	0.0052	0.76	0.009
RR006	19.00	19.00	16.00	15.00	14.00	14.00	12.00	14.00	0	0.0036	−0.42	0.009
RR004	19.00	19.00	19.00	19.50	19.00	17.00	12.00	14.00	1	0.0019	0.95	0.011
RR003	16.75	16.00	13.00	11.00	11.00	1.00	1.00	15.00	1	0.0570	0.90	0.002
Control												
C001	19.00	19.00	19.00	10.00	1.00	1.00	9.00	14.00	0	0.0635	0.66	0.003
C002	19.00	17.00	17.00	17.00	17.00	17.00	15.00	14.00	0	0.0012	−3.04	0.011
C003	17.00	17.00	15.00	15.00	13.00	13.00	13.00	14.00	0	0.0039	−4.23	0.009
C004	19.00	19.00	18.00	17.00	16.00	15.00	9.00	14.00	0	0.0041	0.84	0.009
C006	19.00	17.00	11.00	4.00	3.00	1.00	1.00	14.00	0	0.1335	0.94	0.001
C007	19.00	7.00	3.00	1.00	1.00	1.00	1.00	14.00	0	0.4280	0.86	0.001
C005	19.00	17.00	17.00	19.00	16.00	19.00	15.00	14.00	0			

effects of group on number of indifference points ($F(2, 16) = 5.607$, $p < 0.015$) and number of preferences of the delayed \$20.00 to the immediate \$20.00 ($F(2, 16) = 8.996$, $p < 0.003$). Pairwise comparisons of the group means of the IP and Error data were conducted using the Bonferonni procedure (overall alpha level = 0.08). The mean number of indifference points and the mean number of 'errors' for the participants with brain injury were significantly larger than the means for the naïve participants with brain injury and for the controls. The means for the naïve participants with brain injury and the controls were not significantly different.

Equation (1) was fit to the indifference points for these participants whose data met the above inclusion criteria. The derived *k* parameters and the percent variance accounted for (R^2) are reported in Table 6 for the participants with brain injury and control participants. Generally, Equation (1) did not describe the delay discounting data in Experiment 2 as well as it did in Experiment 1. Although the mean proportion of variance accounted for was high for some of the subjects, for others the proportion of variance was very low or, in some cases, negative, indicating that the indifference curves were inconsistent with a hyperbolic function. Nonetheless, a Wilcoxon rank-sum test (Huck, 2000) was performed to determine whether the ranks of the degrees of discounting (k) were significantly higher for the naïve participants with brain injury than for the controls. The difference in the sums of ranks of the discounting parameters (k) between the groups was not statistically significant ($W_s = 30$, $n_1 = 6$, $n_2 = 6$, $p > 0.10$). The area under the indifference curve (AUC) is also provided in Table 6 for each participant whose data were consistent with delay discounting. The means of the areas under the curve were 0.0089 and 0.0059 for the participants with brain injury and controls, respectively. Again, the difference in the means from the two groups was not statistically significant (one tailed t-test, $t(10) = 1.722, p = 0.12$).

Figure 2 shows aggregate discounting curves for participants whose data were consistent with delay discounting from the naïve participants with brain injury and the control participants from Experiment 2. The proportions of variance accounted for by Equation (1) were 0.66 and 0.35 for the participants with brain injury and control participants, respectively. The solid reference line in Figure 2 shows the best fit line for participants with brain injury and the dashed reference line shows the best fit line for control participants. The derived k value for the aggregate data was higher for participants with brain injury ($k = 0.0022$) than for controls ($k = 0.07278$). Also, the area under the aggregate curve was smaller for the participants with brain injury (AUC = 0.1047) than for controls (AUC = 0.0082). A paired t-test was conducted on the medians of the indifference points from the two groups and the differences were statistically significant ($t(6) = 5.28$, $p < 0.002$).

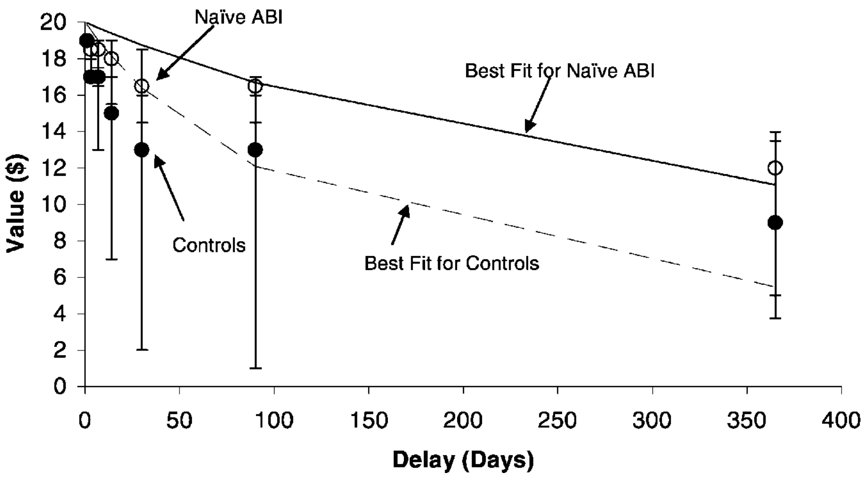

Figure 2. Hyperbolic discounting functions for participants in Experiment 2.

EXPERIMENT 2 DISCUSSION

The results from Experiment 2 suggest that it is not the case that everyone with an acquired brain injury will discount delayed rewards to greater degrees than control participants. Our data show little difference in the temporal discounting patterns between the naïve participants with brain injury and control participants. Nonetheless, the majority of members in both groups engaged in choice behavior that was consistent with previous research on temporal discounting (e.g. Madden et al., 2003, 1999). Our experimental survey results also suggest that all our participants understood the task at hand and could make accurate discriminations between time and money, and therefore potential cognitive limitations were probably not a factor that influenced or biased responding during the experimental procedures.

The naïve participants of Experiment 2 had similar causes of injury, length of time spent in coma, and time since injury to our participants in Experiment 1, and only appeared to distinctively differ in terms of their frequency and severity of problem behaviors. Future research may wish to explore the relationship between behavioral repertoires that contain frequent problem behaviors and the tendency to discount delayed reinforcers. The small sample sizes of this experiment, and our lack of more detailed neurological data regarding the specific brain regions affected by the injury, may be seen as potential limitations; however, they do provide a stimulus for additional research and investigations on delayed reinforcement and temporal discounting exhibited by persons with brain injuries.

In summary, the data obtained from Experiment 2 suggest that not all persons with acquired brain injuries will produce higher levels of temporal discounting than control participants that have no history of brain injury. In fact, some participants with brain injury will actually discount less than controls without a brain injury. There was a wide range of variability in responding by the present experiment's participants, and future research should attempt to control for some of this variation by exploring the potential establishing operations or setting events, both behavioral and neurological, that may influence participant behavior during hypothetical money choice tasks.

GENERAL DISCUSSION

Together, the present two studies expand the literature on temporal discounting to the population of acquired brain injury. Previous research on temporal discounting has focused on comparing populations of people suffering from different forms of addictive disorders such as drug abuse (Bickel & Marsch, 2001), alcohol abuse (Petry, 2001), problem gambling (Dixon et al., 2003), and smoking (Bickel, et al., 1999). Our data extend the generality of the discounting task from consumable addictive disorders to a population that has been repeatedly noted to have impulse control disorders (Anderson et al., 2002). Although some of our participants with acquired brain injuries did not display higher degrees of discounting than control participants, many of them did. Our preliminary findings suggest that there may be a relationship between severity of problem behavior and the ability to complete the discounting task, the display of higher degrees of discounting of delayed rewards, or both when compared with control participants.

An unexpected finding that we uncovered in Experiment 2 was that the newly recruited participants with brain injuries (naïve group) discounted the delayed rewards to a similar degree as control participants. If levels of 'impulsivity' are possibly measured by performance on temporal choice tasks as noted by Critchfield and Kollins (2001), our data suggest that impulsivity is not necessarily a construct that defines all persons with acquired brain injuries. This conclusion is rather speculative, as it could be the case that many of our control participants, college students, were simply impulsive themselves. Furthermore, our sample sizes were relatively small, and larger samples may be needed to add empirical evidence to support these claims. It is also possible that our group of naïve participants with acquired brain injuries emitted different forms of self-rules that governed their behavior differently than participants from Experiment 1. Perhaps after receiving a brain injury many individuals actually tend to become less impulsive, as a form of impulsivity may have been the cause of the injury in the first place (e.g. driving drunk, jumping out of a car, etc.). Comparisons between pre-injury and post-injury levels of delay discounting would most likely be unattainable, but longitudinal post-injury changes might be worth exploring. It may be possible that as post-injury behavioral adaptation improves so do levels of the discounting of delayed rewards.

Our experimental task, of having people with acquired brain injuries choose between hypothetical amounts of money, is also partially limited in terms of potential generality. While the choice money task regularly produces orderly data, that data may have less utility than other procedures for assessment of impulsivity when working with persons with brain injury. Persons living in residential facilities for the rehabilitation of brain injuries often are not exposed to choices between various amounts of money. However, this population is often exposed to choices of other sorts. For example, a staff member may ask a participant whether he would like to go to physical therapy or skip it and watch TV. Using this choice scenario, the temporal choice task might be modified so that choices between various amounts and delays are presented between television watching and physical therapy activity. Here a choice could be stated such as 'Would you rather go to physical therapy for 10 minutes right now or for 30 minutes tomorrow?' or 'Would you rather watch TV for 5 minutes now and go to physical therapy afterwards for 10 minutes, or would you rather go to physical therapy now for 40 minutes, and watch TV for 20 minutes afterwards'. Many permutations between preferred and non-preferred choices could be presented and resulting data could be analyzed in lines with Mazur's model of hyperbolic choice. More objective behavior analytic research needs to be done in the area of delayed rewards, impulsivity, and choice making of persons with acquired brain injuries. This population has been too often neglected by behavior analysts, and successful treatment and rehabilitation may be increased from our understanding of this unfortunate life altering condition.

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REFERENCES

Anderson, M. I., Parmenter, T. R., & Mok, M. (2002). The relationship between neurobehavioural problems of severe traumatic brain injury, family functioning and the psychological well-being of the spouse/caregiver: Path model analysis. *Brain Injury, 16*, 743–757.

Andrews, T. K., Rose, F. D., & Johnson, D. A. (1998). Social and behavioral effects of traumatic brain injury in children. *Brain Injury, 12*, 133–138.

Bickel, W. K., & Marsch, L. A. (2001). Toward a behavioral economic understanding of drug dependence: Delay discounting processes. *Addiction, 96*, 73–86.

Bickel, W. K., Odum, A. L., & Madden, G. J. (1999). Impulsivity and cigarette smoking: Delay discounting in current, never, and ex-smokers. *Psychopharmacology, 146*, 447–454.

Brain Injury Society of America. (2004). Retrieved February 20, 2004, from *http://bisusa.org*

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.

Dixon, M. R., & Falcomata, T. (2004). Preference for progressive delays and concurrent physical therapy exercise in an adult with acquired brain injury. *Journal of Applied Behavior Analysis, 37*, 101–109.

Dixon, M. R., Horner, M. J., & Guercio, J. (2003). Self-control and the preference for delayed reinforcement: An example in brain injury. *Journal of Applied Behavior Analysis, 36*, 367–370.

Dixon, M. R., & MacLin, O. H. (2003). *Visual Basic for behavioral psychologists*. Reno, NV: Context Press.

Dixon, M. R., Marley, J., & Jacobs, E. (2003). Delay discounting of pathological gamblers. *Journal of Applied Behavior Analysis, 36*, 449–458.

Huck, S. W. (2000). *Reading statistics and research* (3rd ed.). New York: Longman.

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

Kirby, K. N., Petry, N. M., & Bickel, W. K. (1999). Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *Journal of Experimental Psychology: General, 128*(1), 78–87.
Madden, G. J., Begotka, A. M., Raiff, B. R., & Kastern, L. L. (2003). Delay discounting of real and hypothetical rewards. *Experimental and Clinical Psychopharmacology, 11*, 139–145.
Madden, G. J., Bickel, W. K., & Jacobs, E. A. (1999). Discounting of delayed rewards in opioid-dependent outpatients: Exponential or hyperbolic discounting functions. *Experimental and Clinical Psychopharmacology, 7*, 284–293.
Madden, G. J., Petry, N. M., Badger, G. J., & Bickel, W. K. (1997). Impulsive and self-control choices in opioid-dependent patients and non-drug-using control participants: Drug and monetary rewards. *Experimental and Clinical Psychopharmacology, 5*, 256–262.
Mazur, J. E. (1987). An adjusting procedure for studying delayed reinforcement. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative analyses of behavior: The effect of delay and of intervening events on reinforcement value* (Vol. 5, pp. 55–73). Hillsdale, NJ: Erlbaum.
Mitchell, S. H. (1999). Measures of impulsivity in cigarette smokers and nonsmokers. *Psychopharmacology, 146*, 455–464.
Myerson, J., & Green, L. (1995). Discounting of delayed rewards: Models of individual choice. *Journal of the Experimental Analysis of Behavior, 64*, 263–276.
Myerson, J., Green, L., & Warusawitharana, M. (2001). Area under the curve as a measure of discounting. *Journal of the Experimental Analysis of Behavior, 76*, 235–243.
Petry, N. M. (2001). Delay discounting of money and alcohol in actively using alcoholics, currently abstinent alcoholics, and controls. *Psychopharmacology, 154*, 243–250.
Petry, N. M., & Casarella, T. (1999). Excessive discounting of delayed rewards in substance abusers with gambling problems. *Drug and Alcohol Dependence, 56*, 25–32.
Rachlin, H., Raineri, A., & Cross, D. (1991). Subjective probability and delay. *Journal of the Experimental Analysis of Behavior, 55*, 233–244.

