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Predictors of delay discounting among smokers: Education level and a Utility Measure of Cigarette Reinforcement Efficacy are better predictors than demographics, smoking characteristics, executive functioning, impulsivity, or time perception

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HIGHLIGHTS

- Delay discounting and other characteristics were measured in ninety-four smokers.
- Education level negatively correlated with discounting.
- Utility Measure of Cigarette Reinforcement positively correlated with discounting.
- Results correspond with several dual-system neuroeconomic models of decision-making.

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ABSTRACT

Ninety-four smokers completed the delay discounting procedure for either hypothetical amounts of money, \$10 (money) and \$1000 (money) or hypothetical amounts of cigarettes (\$10 and \$1000 worth of cigarettes). We investigated how variables previously found to be related to rates of delay discounting accounted for the observed results. These variables included the following: demographic information, smoking characteristics, executive function abilities, impulsivity, time perception, and the Utility Measure of Cigarette Reinforcing Efficacy (UMCE). Education level and UMCE were each significantly correlated with 3 out of 4 of the discounting measures. Moreover, the largest effect sizes observed were between these two measures and the four discounting measures. All potential discounting predictors were also investigated using step-wise linear regression with Bayesian Information Criterion (BIC) analysis — these BIC models revealed that education level and UMCE accounted for large portions of the variance. We conclude that education level and UMCE were the most consistent predictors of discounting. This data is discussed within the framework of a widely accepted neuroeconomic model that suggests that two brain systems separately assess two separate facets of decision-making, and the interplay between these two systems determines self-control in smokers. We hypothesize that education level and UMCE may serve as surrogate measures of the functionality of these two systems and that discounting may be a sentinel measure of self-control.

1. Introduction

The subjective value of a reward is generally diminished when its delivery is delayed (Chung & Herrnstein, 1967; Rachlin & Green, 1972). Individuals suffering from addiction are inordinately affected by delays to reinforcement (Bickel, Koffarnus, Moody, & Wilson, 2013). This effect can be quantified with delay discounting, a procedure that asks an individual to decide between receiving smaller rewards sooner or larger rewards later (Loewenstein & Prelec, 1992; Raineri & Rachlin, 1993). The degree to which an individual subjectively devalues a reward per unit of time until its receipt can be described by a variety of accepted discounting functions (Mazur, 1987; Myerson & Green, 1995; Myerson, Green, & Warusawitharana, 2001; Yi, Landes, & Bickel, 2009, see MacKillop et al., 2011 for a review). Delay discounting has been

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used to further the understanding of substance abuse as this behavior can be conceptualized as preference for the smaller, more immediate rewards of drug use compared to the larger (but delayed) rewards of abstaining (Bechara, 2005; Bickel, Kowal, & Gatchalian, 2006; Bickel & Yi, 2008; Bickel, Yi, Mueller, Jones, & Christensen, 2010).

1.1. The Competing Neurobehavioral Decision Systems model of substance abuse

Several dual decision models have been proposed to account for addiction (Bechara, 2005; Jentsch & Taylor, 1999), and one referred to as the Competing Neurobehavioral Decision Systems (CNDS) model of substance abuse describes the neuronal components of discounting and the disruption of these systems which co-occurs with addiction (Bickel, Jarmolowicz, Mueller, & Gatchalian, 2011; Bickel et al., 2007). This model posits that one's rate of discounting is derived from the interplay between the frontal cortex and the limbic system. As evidence of this, activity in the frontal cortex has been shown to correlate with an individual's assessment and selection of delayed rewards, whereas limbic system activity is related to assessment and selection of immediate rewards (McClure, Ericson, Laibson, Loewenstein, & Cohen, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004). Individuals who abuse illicit substances, a population known to have delay discounting deficits (Bickel et al., 2013), tend to have a corresponding prevalence of dysfunction in these two brain areas. Compared to non-addicted individuals, the pre-frontal cortex of substance dependent individuals has been shown to be smaller in volume on average (Fein, Di Sclafani, & Meyerhoff, 2002), and display neuronal hyperactivity, but hypoactivity during withdrawal (Goldstein & Volkow, 2002). Likewise, chronic drug users tend to show greater dopaminergic activity (Salokangas et al., 2000) and abnormal connectivity in neuronal pathways that are important for reward-based learning (Belin, Jonkman, Dickinson, Robbins, & Everitt, 2009). Finally, greater connectivity and irregular resting state activity within both of these brain regions has been observed in chronic heroin users (Ma et al., 2010).

1.2. General addiction and discounting

In clinical and sub-clinical domains, researchers have examined the effects of trait and state variables on discounting rates for various commodities both across and within individuals (Odum, 2011a,b). Studies suggest that persons dependent upon drugs discount the value of delayed rewards more than healthy controls. This result has been observed in individuals addicted to heroin (Kirby & Petry, 2004; Kirby, Petry, & Bickel, 1999; Madden, Petry, Badger, & Bickel, 1997; Vassileva, Georgiev, Martin, Gonzalez, & Segala, 2011), cocaine (Bickel, Landes, et al., 2011; Camchong et al., 2011; Coffey, Gudleski, Saladin, & Brady, 2003; Heil, Johnson, Higgins, & Bickel, 2006; Kirby & Petry, 2004; Moeller et al., 2002; Petry & Casarella, 1999), and in alcoholics (Bjork, Hommer, Grant, & Danube, 2004; Bobova, Finn, Rickert, & Lucas, 2009; Finn & Hall, 2004; Mitchell, Fields, D'Esposito, & Boettiger, 2005; Petry, 2001; Vuchinich & Simpson, 1998). Further, when those with an addiction make decisions about the drug they are dependent on, the observed rate of discounting is greater than discounting rates for money. Again, this is true for individuals who are addicted to cocaine (Coffey et al., 2003), heroin (Madden et al., 1997; Odum, Madden, Badger, & Bickel, 2000), as well as alcoholics (Petry, 2001).

1.3. Cigarette smoking and discounting

Aberrant discounting can also be seen in those who smoke cigarettes: adult smokers have higher discounting rates than healthy controls (Baker, Johnson, & Bickel, 2003; Bickel, Odum, & Madden, 1999; Bickel, Yi, Kowal, & Gatchalian, 2008; Businelle, McVay, Kendzor, & Copeland, 2010; Johnson, Bickel, & Baker, 2007; Mitchell, 1999; Odum, Madden, & Bickel, 2002; Reynolds, Leraas, Collins, & Melanko, 2009; Reynolds, Richards, Horn, & Karraker, 2004; Rezvanfard, Ekhtiari, Mokri, Djavid, & Kaviani, 2010), as do adolescent smokers (Fields, Leraas, Collins, & Reynolds, 2009; Reynolds et al., 2007). Adult smokers discount more when the commodity is cigarettes, as opposed to money (Bickel et al., 1999), and recent evidence suggesting that rates of delay discounting may predict relapse to smoking (MacKillop & Kahler, 2009; Mueller et al., 2009; Sheffer et al., 2012; Yoon et al., 2007).

The relationship between discounting rates and smoking is, however, mitigated by many factors. Age has been shown to either decrease (Green, Fry, & Myerson, 1994; Green, Myerson, Lichtman, Rosen, & Fry, 1996) or increase (Reynolds, 2004) discount rate, whereas a negative correlation between discounting and IQ was observed in de Wit, Flory, Acheson, McCloskey, and Manuck (2007). Variables specific to one's smoking habit also affect discounting. The amount one smokes tends to be positively correlated with rate of discounting (Epstein et al., 2003; Ohmura, Takahashi, & Kitamura, 2005; Reynolds, 2004; Yi et al., 2008, although see Johnson et al., 2007; Sweitzer, Donny, Dierker, Flory, & Manuck, 2008) and daily smokers tend to discount more than non-daily smokers (Epstein et al., 2003; Ohmura et al., 2005; Yi et al., 2008). Factors affecting the assessment of future rewards, specifically their temporal horizons (Jones, Landes, Yi, & Bickel, 2009) and their executive functioning ability (Bickel & Yi, 2008), have also been shown to affect discount rate in smokers.

1.4. Using the CNDS model to elucidate the multi-facetted relationship between cigarette smoking and discounting: the current study

Related to the CNDS model discussed above, education level correlates with frontal cortex activity (Springer, McIntosh, Winocur, & Grady, 2005) and has been found to be inversely related to discounting rate in smokers (Jaroni, Wright, Lerman, & Epstein, 2004) and others (Appelhans et al., 2011; Bauer & Chytilova, 2010; Jaroni et al., 2004; Kirby et al., 2002; Reimers, Maylor, Stewart, & Chater, 2009). Whereas individuals who smoke have greater dopamine activity in the basal ganglia, a component of the limbic system (Salokangas et al., 2000), and levels of dopamine in this brain region has been shown to be a major determinant of one's ability to express self-control (Montague, Hyman, & Cohen, 2004).

Given the large range of factors shown to relate to the rate of discounting in smokers the current study sought to 1) comprehensively assess previously identified variables affecting discounting in smokers, 2) determine whether these variables systematically affected discounting when the commodities and magnitudes of the rewards assessed are varied, and 3) investigate the interactions among these factors when considering discounting behavior within the framework of the CNDS model. Here for the first time we examine correlations among variables related to the rates of delay discounting for both hypothetical money and hypothetical cigarettes at either $10 or $1000 dollars and then model the subjects' discounting behavior to see which factors were selected as the best predictors. The factors included demographic information including education level, smoking characteristics, executive functioning, impulsivity, time perception and the reinforcement efficacy of nicotine.

Given that the effects of the previous factors and cigarette smoking on discounting were not originally investigated within the framework of the CNDS model and, to our knowledge, have yet to be investigated in a single comprehensive study like the one proposed here, the aims of this study were exploratory in nature, but were also informed by prior information. Given this, the failure to find relationships that have been previously identified in the literature was not assumed to be contradictory, per se, but instead to imply that other factors may explain the individual differences to a better degree in this sample.

2. Method

2.1. Participants

One-hundred twenty-eight participants were recruited through newspaper advertisements and word-of-mouth referrals. The participants had to be at least 18 years of age; smoke at least 20 cigarettes a day; have carbon monoxide (CO) breath level reading 15 parts per million (ppm) or greater; score 5 or greater on Fagerstrom's Test for Nicotine Dependence (FTND; Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991); meet criteria of dependence on the DSM-IV for Cigarettes (American Psychiatric Association, 2000); and have no plans to quit smoking within the next 30 days. Individuals were excluded from participation if they were pregnant or if they presented significant medical or psychiatric conditions. Following written consent, the participants were required to pass an Alco-Sensor III breathalyzer test. Ninety-four participants (59 males; average years of age = 40.4, SD = 10.6) met the inclusionary requirements for participation and completed the experimental session. As subjects were required to have a CO breath level of 15 ppm or greater at the time of testing (which lasted approximately 2 h) the participants were not experiencing nicotine deprivation during the procedure.

2.2. Procedure

During the experimental session participants gave informed consent and completed the following pen-and-paper based assessments: Ammons and Ammons (1962) quick test to estimate IQ; a Utility Measure of Cigarette Reinforcing Efficacy questionnaire (UMCE; an adaptation of Griffiths, Troisi, Silverman, & Mumford, 1993 without experiential rewards), which is explained in more detail below; the Barratt Impulsivity Scale—Version 11 (Barratt, 1985); the Color–Word Stroop Task (Stroop, 1935) within the color naming portion of the Delis–Kaplan Executive Function Systems test (D-KEFS, Delis, Kaplan, & Kramer, 2001); and two Cigarette Equivalence Questionnaires (CEQ) for $1000 and $10.

The Barratt Impulsivity Scale—Version 11 interleaves three sets of questions which measures a subject's impulsivity along the three accepted facets of the disorder: motor, planning, and attention (Evenden, 1999). In the D-KEFS version of the Color–Word Stroop Task participants are engaged in four experimenter-guided sets of trials. In the first (color-naming) participants say aloud the color of a square that is shown to them, in the second (word-reading) they say aloud the word (in black and white shading) presented, the third (Incongruent) they say aloud the color of the font while refraining from saying the color–word, and in the final set (Interference effect) participants again say aloud the color of the font, but if a box surrounds the word then the subjects instead say aloud the word and ignore the font color. The subject's score is composed of the number of times they correctly perform each task. Finally, the CEQ asks subjects to list the number of packs of cigarettes whose receipt "right now" would be just as attractive to the participant as receiving $1000 and $10, respectively.

The remaining assessments were administered on a computer: the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtis, 1993); a Time Reproduction Task (see McDonald, Schleifer, Richards, & de Wit, 2003 for a similar procedure) where participants reproduced 3, 6, 10, 18, 30, 56, and 100 s in ascending order; and 4 delay discounting assessments for money and for cigarettes (explained in more detail below). A subject's performance on the WCST was composed of the number of trials (out of 60 possible) completed, the total number of errors a subject completed, the total number of times they erroneously selected a card that would have been correct under the previous rule, and the total number of errors committed that did not conform to either the current or prior rule. Following the experimental session each participant was compensated twenty-five dollars for their time. Nineteen participants made subsequent visits to the laboratory to engage in other experimental activities that were not analyzed pursuant to the present report, see Mueller et al. (2009) for this data.

2.3. The Utility Measure of Cigarette Reinforcing Efficacy

The Utility Measure of Cigarette Reinforcing Efficacy (UMCE) is obtained via a paper-and-pencil questionnaire. Subjects were presented with twenty-one amounts of money on a single piece of paper: $0.25, $0.50, $0.75, $1.00, $1.25, $1.50, $1.75, $2.00, $2.50, $3.00, $3.50, $4.00, $4.50, $5.00, $6.00, $7.00, $8.00, $9.00, $10.00, $11.00, and $12.00. For each amount, the subject chose between hypothetically receiving the money or hypothetically smoking 1.5 cigarettes in the next hour. The questionnaire thus assesses the participant's utility for cigarettes versus money. Assuming a subject would initially select to receive cigarettes over money, but then change their preference to money as the amount increased, the measure derived from this questionnaire is the midpoint, also called the changeover point, between the last money value in which "Cigarettes" are selected and the first money value in which "Money" is selected.[1]

2.4. Delay discounting procedure

Delay discounting was assessed using hypothetical gains of $10 (money) and $1000 (money), and the number of cigarettes deemed equivalent to $10 and $1000 by the participant on the CEQ (described above). The order of presentation of assessments for the $10-value and $1000-value amount of each of the commodities was counterbalanced across participants. The computerized assessment was administered four times, once for each commodity. Each assessment consisted of seven (hypothetical) delays: 1 day, 1 week, 1 month, 6 months, 1 year, 5 years, and 25 years, which appeared in this order. During a block, the participant was presented with a series of binary choices between a hypothetical small, immediate reward and a hypothetical large reward to be received at the given delay. Within a block of trials the immediate reward varied according to the participant's last choice; the large reward, however, remained constant throughout the entire assessment (i.e., either $10 or $1000 in value). Based on the choices made in a delay series, an indifference point was extracted from the data using a computer program that implemented a diminishing-adjustment algorithm (see Kowal, Yi, Erisman, & Bickel, 2007). The indifference points from each reward type were fitted using Eq. (1) originally proposed by Mazur (1987),

$$V = \frac{A}{1 + kD} \tag{1}$$

where V is the subjective value of a reward having value A, delayed by D time units, and discounted by a rate dependent upon the subject-specific parameter k which was estimated with nonlinear regression. Higher values of k correspond to steeper discounting rates. As the distribution of k is well described with a log-normal distribution, we took the natural logarithm of k so that it would be approximately normal. This transformation noticeably reduced skew in the discounting measures, as the raw k discounting measures for the four discounting outcomes had skew values ranging from 4.82 to 9.25 while the log-transformed skew values ranged from −0.84 to 0.49. In light of the reduction in skew and the symmetric distribution of $\ln(k)$ observed via histogram, all subsequent discounting analysis was based on $\ln(k)$ values to better satisfy parametric modeling assumptions.

[1] Note: a standardized model to quantify the psychometric properties of the participants responding on this procedure has yet to be created, meaning that changeover point was the only measure available for analysis.

2.5. Statistical analysis

Prism 6.0 (GraphPad Software Inc.) was used to estimate k parameters for discount rate based on Eq. (1), and to generate graphs of the data. All further analyses were conducted with SAS version 9.3. Paired t-tests and Pearson correlations were used to compare discounting outcomes between cigarettes and money. For binary variables (such as gender), mean discount rates were assessed using two sample t-tests. The nonparametric Spearman correlations were used to assess relationships between discounting $\ln(k)$ values and other study variables. This rank-based correlation is an appropriate measure of association between ordinal variables even when the variables under study are not normally distributed. We chose to report Spearman correlations for all measures to simplify reporting since the corresponding hypothesis tests are suitable for all measures under investigation.

Scientific overreliance on statistical significance testing via the use of p-values has come under increased scrutiny as of late. Concerns about reproducibility have been noted (Boos & Stefanski, 2011), and the issue of multiplicity correction is surrounded by disagreement and controversy (e.g., Rothman, 1990; Young & Karr, 2011). Nonetheless, p-values remain widely used in many fields of study. Given their complementary nature, all p-values are accompanied by measures of effect size. In this report p-values (which reflect the probability that the observed data are compatible with a presupposed null association) and effect sizes (which describe the strength of the relationship observed in the data) are presented together to offer a more comprehensive picture of the findings.

Effect sizes are reported as Cohen's d for two group comparisons, correlations for the association of numeric variables, and η^2 values for model-based results. By convention (see Cohen, 1977), Cohen's d values of 0.2, 0.5, and 0.8 are small, medium, and large respectively. For Pearson correlation, values of 0.1, 0.3, and 0.5 in magnitude are considered small, medium, and large. For η^2, values of 0.02, 0.15, and 0.35 are small, medium, and large respectively. Note that Spearman correlation is identical to Pearson correlation on the ranks of the original variables and these same conventions are adopted here.

Stepwise linear regression was used to select the parameters that best predicted the observed rates of discounting for the four commodities as chosen by the Bayesian Information Criterion (BIC, Schwarz, 1978). All pertinent variables collected in this procedure (this includes gender and all variables listed in Table 1A) were used as candidate predictors. Each of the four discounting measures was considered as an outcome variable in separate model selection exercises. Stepwise variable selection was used to determine which variables were included in the final models, and BIC was used as the statistical criterion to add or remove variables within the stepwise framework. BIC is a well-known statistical information criterion that assesses the likelihood of a model plus a penalty for model complexity. If two models are equally likely in light of the observed data then BIC will favor the simpler model that has fewer parameters; low values of BIC correspond to models that are more parsimonious. Given this constraint, variables that account for the greatest amount of unique variability are more likely to be selected, meaning that the potential for multicolinearity between the variables selected will be low.

Table 1
Summary statistics (A) and frequency counts (B) for demographic variables and smoking-related behaviors. Key: FTND = Fagerstrom score for nicotine dependence, CO = carbon monoxide, WCST = Wisconsin Card Sorting Task, BIS = Barratt Impulsivity Scale—11.

A

Amount	Average	SEM	*N*
Age	40.39	1.09	94
IQ	38.69	0.45	94
Cigarette equivalence $10	4.50	0.31	94
Cigarette equivalence $1000	587.90	120.67	94
Fagerstrom's Test for Nicotine Dependence	7.29	0.15	94
Breath CO level (unit)	26.84	0.99	94
Number of quit attempts	2.90	0.43	94
Cigarettes smoked per day	26.87	0.95	94
Years of education	13.16	0.18	94
Utility Measure of Cigarette Reinforcing Efficacy	3.81	0.34	94
BIS total score	64.82	1.20	91
BIS nonplanning factor	24.93	0.58	92
BIS attention factor	16.05	0.39	92
BIS motor factor	23.87	0.45	92
WCST: trials	105.32	2.47	94
WCST: total errors	33.76	2.27	94
WCST: perseverative errors	17.07	1.30	94
WCST: non-perseverative errors	16.64	1.18	94
Stroop: color name	63.21	1.23	94
Stroop: incongruent	116.40	2.78	94
Stroop: interference effect	99.32	2.68	94
Stroop: word reading	48.22	1.01	94
Temporal discrimination (average)	49.28	4.60	92

B

Demographics: Frequency statistics	*N*
Ethnicity	
Caucasian	54
African Americans	39
Native Americans	1
Gender	
Male	59
Female	35

The stepwise selection procedure is an iterative algorithm that alternates between adding variables that improve predictive capacity and removing variables that are made obsolete by new additions. At each step currently included variables are removed in any case where BIC improves as a result. If BIC cannot be improved by removing any included variables, then the next predictor added is chosen based on whichever candidate variable improves BIC the most. The procedure continues in this fashion until neither the addition nor removal of any variables can improve BIC. The GLMSELECT procedure (SAS version 9.3, Cary, NC) was used to accomplish variable selection and further detail can be found in the appropriate documentation.

3. Results

Summary statistics of age, IQ, cigarettes smoked per day, initial CO, and number of prior quit attempts, education level, smoking characteristics, executive functioning, time perception, impulsivity, and the reinforcement efficacy of nicotine are reported in Table 1A, frequency scores for ethnicity and gender of reported in Table 1B.

3.1. Relationship between discounting of hypothetical cigarettes and hypothetical money

In correspondence with previous literature (Bickel et al., 1999) the discounting of cigarette rewards was significantly higher, when compared to discounting for money, at both the \$10 ($t = 3.28$, df $= 88$, $p = .0015$, $d = 0.36$) and the \$1000 ($t = 3.73$, df $= 89$, $p = .0003$, $d = 0.40$) levels.

3.2. The relationship between demographics and smoking related variables with discounting

Caucasian and African American individuals differed by a significant amount for the \$10 (money) discounting condition (\$10 money: $t = 2.21$, df $= 90$, $p = .0295$, $d = 0.47$), but did not statistically differ on the other discounting conditions. Gender differences were non-significant for all discounting conditions. Neither age nor IQ showed a significant relationship with any of the discounting measures (see Table 2).

Of the variables related explicitly to smoking, performance on the \$10 Cigarette Equivalence Task significantly correlated, negatively so, with discounting for \$10 worth of cigarettes (see Table 2), but all other measures on this task, as well as all other behaviors associated with smoking (i.e., prior quit attempts, number of cigarettes smoked in a day, FTND score, and CO breath level) did not show statistically significant relationships with discounting (see Table 2).

3.3. The relationship between education level and discounting

Fig. 1 shows individuals' log-transformed discounting rates, ln(k) plotted against their education level. Education level was significantly and negatively correlated with discounting rates for \$1000 (money), \$10 worth of cigarettes, and \$1000 worth of cigarettes (see Table 2).

3.4. The relationship between executive function variables and discounting

On the Wisconsin Card Sorting Task, increases in total trials completed, total errors, and total perseverative errors committed were significantly correlated with increases in discounting rates for \$1000 (money) and \$10 worth of cigarettes, whereas non-perseverative errors were only correlated with discounting for \$10 worth of cigarettes (see Table 2). The averaged time-reproduction discrimination was significantly correlated with discounting for \$1000 (money) and \$10 worth of cigarettes. Stroop task performance was only significantly correlated with discounting for \$10 worth of cigarettes (see Table 2). Finally, responses on all four measures (non-planning, motor, non-motor, attention, and total) of the Barratt Impulsivity Scale were significantly correlated with any of the discounting measures.

Table 2
Spearman (r) correlations among variables related to discounting. Sample sizes in this table range from $n = 87$ to $n = 94$. Key: FTND = Fagerstrom score for nicotine dependence, CO = carbon monoxide, WCST = Wisconsin Card Sorting Task, BIS = Barratt Impulsivity Scale—11.

	ln(k) money		ln(k) cigarettes	
Amount	\$10	\$1,000	\$10	\$1,000
Age	−0.02	−0.03	−0.04	0.14
IQ	−0.04	−0.13	−0.11	−0.15
Cigarette aquivalence \$10	−0.14	−0.13	−0.27**	−0.16
Cigarette equivalence \$1000	0.08	−0.12	0.13	0.00
Fagerstrom's test for nicotine dependence	0.13	0.13	0.09	−0.03
Breath CO level (unit)	−0.16	−0.01	−0.18	−0.08
Number of quit attempts	0.06	0.00	0.08	0.11
Cigarettes smoked per day	−0.01	0.19	0.05	0.03
Years of education	−0.11	−0.29**	−0.29**	−0.31**
Utility measure of cigarette reinforcing efficacy	0.35***	0.23*	0.19	0.23*
BIS total score	0.03	0.10	0.11	−0.01
BIS nonplanning factor	−0.02	0.15	0.12	0.01
BIS attention factor	0.11	0.04	0.16	0.00
BIS motor factor	0.03	0.02	0.02	0.00
WCST: Trials	0.08	0.23*	0.26*	0.19
WCST: Total errors	0.08	0.20*	0.24*	0.20
WCST: Perseverative errors	0.13	0.24*	0.26*	0.19
WCST: Non perseverative errors	0.03	0.18	0.21*	0.21
Stroop: Color name	0.14	0.18	0.26*	0.19
Stroop: Incongruent	0.05	0.19	0.17	0.19
Stroop: Interference effect	0.05	0.18	0.15	0.17
Stroop: Word reading	0.01	0.14	0.13	0.15
Temporal discrimination (average)	−0.01	0.25*	0.21*	0.12

Significance legend		Effect size legend	
*	p<0.05	> small	positive
**	p<0.01	> small	negative
***	p<0.001	below small	either

3.5. The relationship between Utility Measure of Cigarette Reinforcing Efficacy and discounting

Fig. 2 displays individuals' log-transformed discounting rates, ln(k), plotted against the averaged Utility Measure of Cigarette Reinforcing Efficacy (UMCE). The UMCE score was significantly correlated with the discounting rates for \$10 (money), \$1000 (money), and \$1000 worth of cigarettes. UMCE was positively correlated with discounting rates for \$10 worth of cigarettes, but not significantly (see Table 2).

3.6. Are education level and Utility Measure of Cigarette Reinforcing Efficacy associated with rates of discounting?

In the step-wise linear regression analysis, BIC identified the most parsimonious model of discounting for \$10 (money) to include five variables: three that had an effects size above small (UMCE, number of cigarettes smoked per day, and FTND) and two that were below small (IQ and the \$1000 Cigarettes Equivalence questionnaire; see Table 3). For \$1000 (money) discounting, two variables, each with an effect size greater than small (education level and gender) were identified (see Table 3). For discounting for \$10 and \$1000 worth of cigarettes only one variable (education level) was identified as the most parsimonious predictor, and in both models the effect sizes were above small (see Table 3).

4. Discussion

In the following study we sought to characterize the best predictors of discounting for delayed amounts of cigarettes and money in smokers

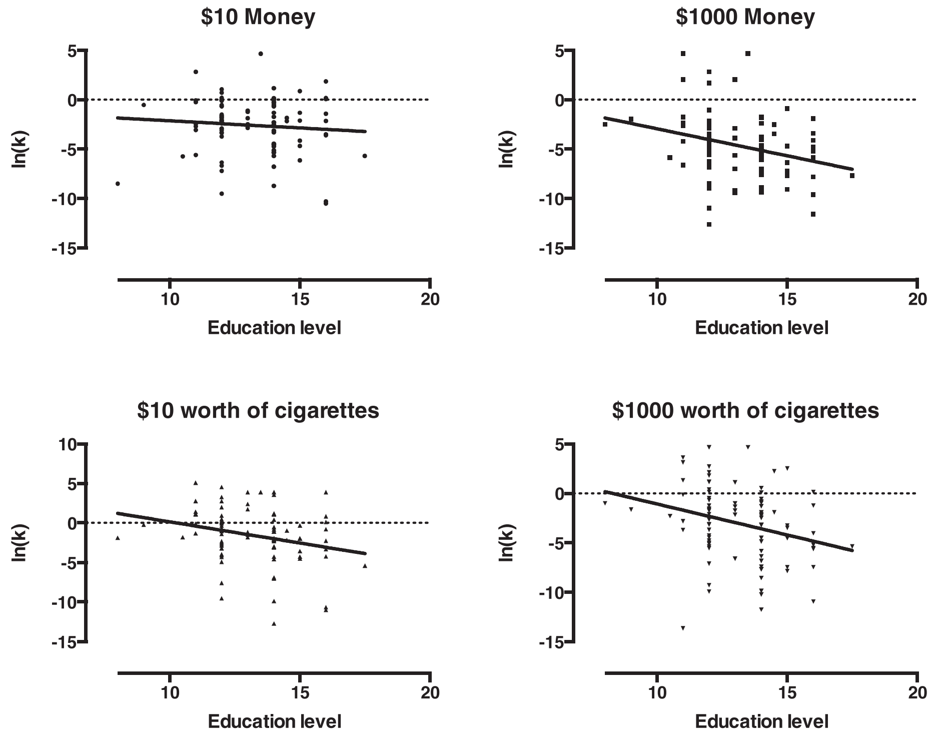

Fig. 1. Individual's log-discounting rates were plotted against their own education level. The figures suggest that discounting changes systematically with education level. Statistical analyses on the whole group confirmed that discounting for $1000 worth of hypothetical money, $10 worth of hypothetical cigarettes, and $1000 worth of hypothetical cigarettes are significantly correlated, negatively so, with education level.

among several factors that have been previously shown to influence these measures; the factors investigated included demographic variables (i.e., age, gender, IQ, and education level), smoking characteristics (number of cigarettes that were equivalent to $10 and $1000, initial CO, number of quit attempts, Fagerstrom score for nicotine dependence: FTND, and cigarettes smoked per day) executive function measures (the Wisconsin Card Sorting Task: WCST and the Stroop test), the Barratt Impulsivity Scale, temporal discrimination, and Utility Measure of Cigarette Reinforcing Efficacy (UMCE). Of these variables, education level and UMCE were the strongest and most consistent predictors of

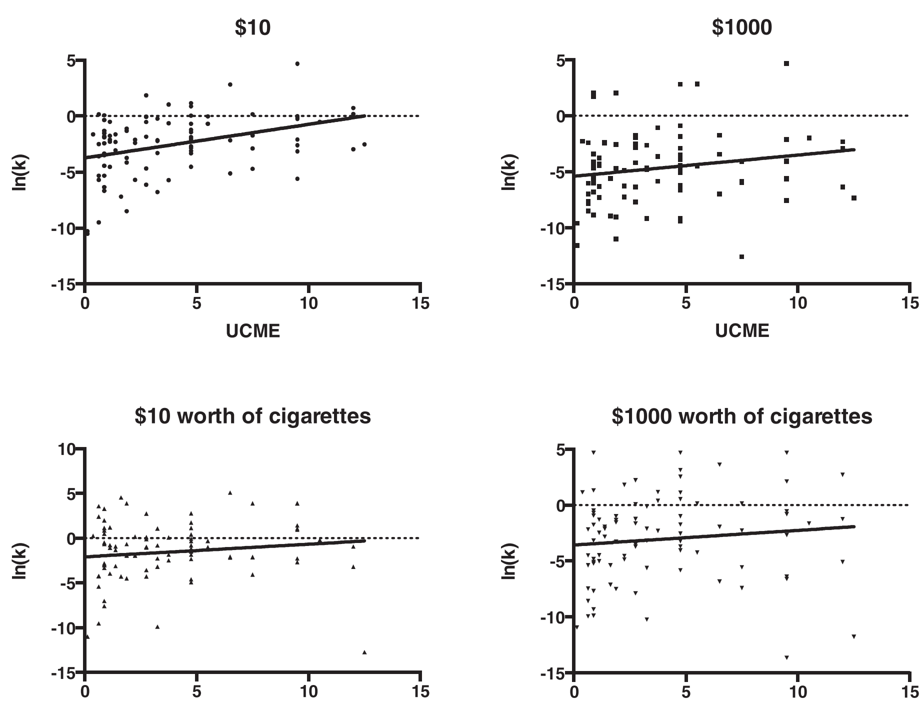

Fig. 2. Individual's log-discounting rates were plotted against their own score on the Utility Measure of Cigarette Reinforcing Efficacy (UMCE). The figures suggest that discounting changes systematically with the midpoint of utility. Statistical analyses on the whole group confirmed that discounting for $10 worth of hypothetical money, $1000 worth of hypothetical money, and $1000 worth of hypothetical cigarettes are significantly correlated, positively so, with utility.

Table 3
Variables selected by the step-wise linear regression model using Bayesian Information Criterion (BIC) selection methods. Sample sizes in this table range from $n = 87$ to $n = 91$. The final BIC score for each model is listed. The variables are arranged by the order in which they entered the model; no steps that entered the model were ever removed. The variables are color coded by their partial eta square a value, which reflects the degree to which each variable accounts for the data, no values greater than a small effect were observed.

	ln(k) money		ln(k) cigarettes	
	$10	$1000	$10	$1000
n	90	91	87	87
BIC (final model)	164.18	205.48	208.39	229.34
Step 1	UMCE η2 = 0.15 coef: 0.29	Education η2 = 0.039 coef: 1.48, F to M	Education η2 = 0.069 coef: −0.58	Education η2 = 0.077 coef: −0.67
Step 2	Cigs per day η2 = 0.041 coef: −0.15	Gender η2 = 0.066 coef: −0.52		
Step 3	FTND η2 = 0.027 coef: 0.71			
Step 4	IQ η2 = 0.017 coef: −0.14			
Step 5	CEQ $1000 η2 = 0.011 coef: <.01			

Effect size legend

> small
< small

the four discounting measures observed in this study; specifically, the lower one's education level the more one tended to discount future rewards, and the higher one scored on the UMCE the more one tended to discount. This was confirmed using both Spearman correlations and step-wise linear regression with BIC.

4.1. Consistencies and inconsistencies of current findings with prior findings

Consistent with prior findings, CEQ for $10, lower education level, a greater UMCE score, all four aspects of the WCST (specifically a larger number of errors and a greater number or trials need to complete the task), greater accuracy on the color naming portion of the D-KEFS Stroop task, and more accurate average temporal reproduction were correlated with greater discounting for $1000 (money) and/or $10 worth of cigarettes. In contrast, greater discounting for $10 (money) and $1000 worth of cigarettes was significantly correlated with only 1 (UMCE) or 2 (education level and UMCE) variables, respectively. These results suggest that the subjects may have engaged different decision-making processes for $1000 (money) and $10 worth of cigarettes compared to $10 (money) and $1000 worth of cigarettes, because 1) a $1000 dollars is objectively more valuable, and 2) perishable rewards are discounted to a greater extent if they cannot be consumed before expiration or desire for the reward is sated (Charlton & Fantino, 2008). Subjects may have engaged executive function-taxing decision processes to choose between more valuable units of the commodities, but made more cursory decisions for less valuable rewards.

All four scores on the WCST (specifically a larger number of errors and a greater number of trials need to complete the task) were significantly correlated with greater discounting for $1000 (money) and three out of the four were correlated with greater discounting for $10 worth of cigarettes. Few studies have attempted to use the WCST to characterize the discounting behavior of individuals who smoke cigarettes (see Bickel & Yi, 2008), however WCST performance has been used to characterize the differences of smokers who are and are not in a nicotine deprived state (Lyvers, Maltzman, & Miyata, 1994). Interestingly, Mueller et al. (2009) found that aspects of WCST performance were predictive of relapse in an experimental nicotine deprivation procedure, however it is important to note that the Mueller et al. (2009) study used a subset of participants that partook in the current study. Combined these results suggest that use of the WCST to predict whether individuals who smoke will discount future rewards more or are more susceptible to relapse warrants further study.

Inconsistent with prior findings the following variables were found to have an insignificant correlative relationship with some or all discounting measures: age, IQ, FTND score, Breath CO, number of prior quit attempts, cigarettes smoked per day, all four measures of the Barratt Impulsivity Scale, and three out of the four measures of D-KEFS Stroop performance. As this current study was exploratory in nature, the failure to find relationship should not be considered as contradictory to prior findings. Indeed, it is difficult to extract from a null result whether a type II error (i.e., a factor did indeed influence discounting but was not significantly captured in this data) has occurred or that a previously reported relationship does not exist here. The best way to investigate, in the future, these null findings would be to perform further analyses where subjects are better matched on the metrics in question (e.g., similarly aged, have similar IQ score, similar FTND score, etc.) and perform a power analysis based on the findings presented here to determine the number of subjects needed to definitively answer the above question.

4.2. Education level and Utility Measure of Cigarette Reinforcing Efficacy as sentinel measures of the Competing Neurobehavioral Decision Systems

The present results suggest the importance of delay discounting as a behavioral marker for self-control (Bickel et al., 2013) under the CNDS theory of substance abuse, as behaviors (i.e., education level and UMCE) that reflect the functionality of two brain regions important in self-control were found to correlate with discounting. This theory (Bickel, Jarmolowicz, et al., 2011; Bickel et al., 2007) contends that activation of evolutionarily older limbic and para-limbic brain regions is responsible for the evaluation and selection of immediate reinforcers; whereas, the more recently evolved prefrontal cortical structures undergird consideration and selection of larger, but delayed, rewards. Delay discounting rates, which reflect an individual's general tendency to devalue future events, are thus interpreted as an index of the relative strengths of these two competing systems in the participants. As such, the related higher education levels and lower delay discounting rates we observed in our smokers may result from increased activation in the prefrontal cortex, while the related higher discounting rates and corresponding higher measures of reinforcing efficacy suggest greater activation in the limbic system.

The Spearman correlations analysis between discounting and the independent variables measured in this study (see Table 2) yielded a number of noteworthy findings. First, education level and UMCE were significantly negative and positive, respectively, correlated with 3 out of the 4 discounting measures investigated in this study (see Figs. 1 and 2), and of the significant correlations observed UMCE or education level yielded the largest effect size for each discounting measure investigated.

Secondly, we used stepwise multiple linear regression modeling coupled with BIC selection criteria to find the least number of variables that best characterize discounting (see Table 3). For all four models, UMCE or education level were the first initial steps used by the modeling algorithm to account for the data. For discounting of both $10 worth of cigarettes and $1000 worth of cigarettes, the most parsimonious model of the data identified by this analysis used only education level. For discounting of $10 (money), UMCE remained the best predictor of the data, as evidence by the partial η^2 effect size, given all the other independent variables selected by the BIC algorithm. Finally, for $1000 (money), only two variables were selected with gender being a better predictor than education level. Combined, these results suggested that individual differences among smokers in rates of discounting are best explained by education level and UMCE.

Finally, these results are also in-line with the theoretical concept of reinforcement pathology (Bickel, Jarmolowicz et al., 2011; Bickel, Johnson, Koffarnus, MacKillop, & Murphy, 2014; Carr, Daniel, Lin, & Epstein, 2011). This term refers to the two orthogonal motivational mechanisms by which an individual can become addicted to a substance: 1) through receiving excessive reinforcement from the substance, or 2) through overvaluation of immediate rewards; specific to the CNDS model, overexcitation of the limbic system is believed to undergrid category 1, whereas prefrontal cortex dysfunction is believed to be an underlying cause of category 2 (Bickel, Jarmolowicz, et al., 2011). Bickel et al. (2014) have argued that this concept has the potential to be utilized, in the future, to create personalized recovery plans as the category in which a patient falls is expected to determine which therapy options will be most effective. With this in mind, the current results suggest that 1) UMCE may be a useful future tool for screening the addicted and determining which motivational pathology they suffer from, and 2) the prophylactic properties of education level may be different for individuals who fall in either of these two categories. However, future research will be required to confirm both of the assertions.

4.3. Limitations

Limitations of the present study include the fact that the exclusion criterion may have imposed restrictions on the demographic variability within our sample; specifically, only individuals classified as nicotine dependent according to the DSM-IV (American Psychiatric Association, 2000) were included in this study. Secondly, a growing prevalence of individuals who smoke are characterized as light — or light and intermittent — smokers (Coggins, Murrelle, Carchman, & Heidbreder, 2009), and it is unknown whether the findings of the current study could be extended to individuals who meet this criteria. Future studies will need to be undertaken to determine the effect that education level and UMCE have on a more heterogeneous populations of smokers.

The current study examined relationships between rates of delay discounting among smokers and measures of behaviors found previously to affect this measure. Analyses showed that two variables, education level and the Reinforcement Efficacy of Cigarettes (i.e., UMCE), contributed to predicting rates of discounting for delayed money and cigarettes. The current results were consistent with, and may be considered a validation of, the neuroeconomic view that decision-making during delay discounting tasks is determined by two competing neural systems.

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Contributors

AGW and ETM wrote the manuscript, CTF and RDL analyzed the data. BPK, RY, and WKB designed the study and collected the data. All authors have approved the final manuscript.

Conflict of interest

The authors have nothing to disclose.

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