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Reliability and Validity of Measures of Impulsive Choice and Impulsive Action in Smokers Trying to Quit

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Cross-sectional research suggests that smokers are more impulsive than are nonsmokers, but few studies have examined relations between impulsiveness and later success in quitting smoking. The purpose of this study was to investigate the reliability and predictive validity of facets of impulsiveness in adult smokers trying to quit. Baseline behavioral measures of impulsive choice (assessed with a delay discounting task) and impulsive action (assessed with a measure of behavioral disinhibition) were used as predictors of smoking cessation success over 12 weeks. The sample included 116 adult (18 years old or older) daily smokers from central New Jersey. Impulsive choice, impulsive action, and self-reported impulsiveness were not significantly related to one another at baseline. Impulsive choice had high test–retest reliability from pre- to postquit, whereas impulsive action was less stable. Test–retest reliability from prequit to 3 weeks' postquit was moderated by achievement of 7-day abstinence. Baseline impulsive action was significantly negatively related to quitting for at least 1 day in the first 2 weeks of a quit attempt and of prolonged abstinence (no relapse over the next 10 weeks). Baseline impulsive choice was robustly associated with biochemically verified 7-day point-prevalence abstinence 12 weeks' postquit, such that those with lower delay discounting were more likely to achieve abstinence. Facets of impulsiveness appear to function largely independently in adult smokers, as indicated by their lack of intercorrelation, differential stability, and differential relations with abstinence. Impulsive action may impede initial quitting, whereas impulsive choice may be an obstacle to maintaining lasting abstinence.

Keywords: smoking cessation, impulsiveness, delay discounting, behavioral disinhibition, tobacco dependence

Impulsiveness is a broad concept relevant to self-control and optimal decision making that has been implicated in several forms of psychopathology (e.g., de Wit, 2009; Dick et al., 2010), including tobacco dependence (Mitchell, 1999). Impulsiveness is typically treated as trait-like, and between-subjects analyses have shown that smokers tend to be more impulsive than never or

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ex-smokers (Bernow et al., 2011; Bickel, Odum, & Madden, 1999; Mitchell, 1999, 2004a), although drug use may influence impulsiveness acutely as well (Perry & Carroll, 2008). Among smokers, impulsiveness may be a useful marker of relapse risk, either because greater impulsiveness induces relapse risk or because impulsiveness on behavioral tasks may share a common cause with relapse (Perry & Carroll, 2008). Self-reported trait-impulsiveness was found to predict a return to smoking within 24 hr of participating in a smoking cessation workshop in one study (Doran, Spring, McChargue, Pergadia, & Richmond, 2004), and this return to smoking may be related to worse craving and anxiety in the first 48 hr of abstinence among more impulsive smokers (VanderVeen, Cohen, Cukrowicz, & Trotter, 2008). Identifying individuals whose elevated impulsiveness may place them at risk for continued smoking during a smoking cessation attempt may be useful in understanding specific obstacles to abstinence in highly impulsive smokers and developing specific interventions to address these.

To serve as a useful marker of smoking relapse risk, however, the construct of impulsiveness must be validated, and reliable measures must be developed. Sound psychometric properties of measures will be a prerequisite for use as a predictive marker of success in quitting. The concept of impulsiveness is quite broad and encompasses diverse behavioral and self-reported phenomena (e.g., impatience, acting without thinking, prioritizing immediate pleasure over long-term gains). Clarifying the boundaries and breadth of impulsiveness is important in efforts to use it as a marker of clinical outcomes. Recent evidence suggests that facets of the impulsiveness construct are independent (Dick et al., 2010; Dougherty et al., 2009; Reynolds, Ortengren, Richards, & de Wit, 2006). In both rat and human models, impulsive choice (i.e., prioritizing short-term gains over long-term gains) has been shown to be distinct from impulsive action (i.e., acting without thinking; Broos et al., 2012; de Wit, 2009). In humans, self-reported impulsiveness is also unrelated to behavioral measures of impulsive choice and impulsive action (de Wit, 2009; Reynolds et al., 2006; Stanford et al., 2009). As such, a broad measure of impulsiveness is probably not an appropriate candidate marker for relapse risk, and measures of these specific facets of impulsiveness are better candidates for study.

In humans, impulsive choice is often measured with the intertemporal choice paradigm in which an individual is presented with a choice between rewards of varying magnitudes separated in time. This paradigm can be used to estimate individual differences in delay discounting, or the extent to which one devalues rewards that one has to wait to obtain. In delay discounting tasks, participants are required to choose between smaller rewards available sooner, and larger, delayed rewards. The degree to which subjects opt for the smaller rewards, over delayed rewards that are objectively larger, measures the extent to which they devalue the delayed rewards. This form of impulsive decision making is relevant to quitting smoking because smoking provides the user with an immediate reward, but quitting smoking provides more positive health outcomes in the future (Chapman, 2005; Odum, Madden, & Bickel, 2002).

Delay discounting can be measured in different ways (e.g., computing a discounting rate that requires specification of a discounting function, computing area under the discounting curves). Evidence suggests that area under the discounting curve is preferable to computed discounting rates because it is an empirical discounting function and is therefore robust to misspecification of discounting functions (e.g., hyperbolic, exponential; Myerson, Green, & Warusawitharana, 2001). Area under the curve (AUC) is also less prone to skewness than discounting rates. As such, these improved measurement properties make it a stronger candidate marker than discounting rates, although past evidence has documented elevations in discounting rates among users of tobacco and other substances (Baker, Johnson, & Bickel, 2003; Bickel, Odum & Madden, 1999; Mitchell, 1999; Reynolds, 2004; Reynolds et al., 2007) and among those who fail to maintain abstinence in smoking cessation programs (Goto, Takahashi, Nishimura, & Ida, 2009; Krishnan-Sarin et al., 2007; MacKillop & Kahler, 2009; Yoon et al., 2007) and laboratory paradigms (Dallery & Raiff, 2007; Mueller et al., 2009). As such, there are both cross-sectional and longitudinal data supporting a link between impulsive choice, as indexed by discounting rates, and smoking.

To serve as a marker of relapse risk, any measure must have adequate internal consistency and reliability. Past research among healthy adults suggests that measures of impulsive choice have reasonable test–retest reliability over short (e.g., 10-day) and long (e.g., 3-month) intervals (Ohmura, Takahashi, Kitamura, & Wehr, 2006; Weafer, Baggott, & de Wit, 2013). Other evidence suggests that impulsiveness may vary across states, however. For example, researchers have found that young-adult smokers show greater delay discounting for monetary and cigarette rewards when nicotine-deprived than just after smoking (Field, Santarcangelo, Sumnall, Goudie, & Cole, 2006). Others have found that this deprivation effect on discounting only reaches significance in smokers with attention-deficit/hyperactivity disorder (ADHD; McClernon et al., 2008) or only holds for cigarettes and not for monetary rewards (Mitchell, 2004b). Recent research has shown that change in affect, particularly increases in positive affect and arousal levels, is moderately associated with decreased delay discounting within healthy adult subjects (Weafer et al., 2013). Animal research also suggests that acute doses of nicotine increase impulsive choice in a dose-dependent manner (Dallery & Locey, 2005). Thus, some evidence points to instability in impulsive choice across mood or nicotine deprivation states. For this reason, it is important to explore the extent to which impulsive choice varies across nicotine deprivation levels.

Another facet of impulsiveness, impulsive action, can be measured in many ways (Dick et al., 2010; Mitchell, 2004a), and one common method is to assess the degree to which an individual struggles to inhibit a response (e.g., not pressing a go button in the presence of a stop signal) when a response is not in his or her best interest (e.g., when commission errors are punished or not rewarded). In various laboratory paradigms (e.g., Go/No Go, Go/Stop, Continuous Performance Test), individuals are instructed to inhibit motor responses when signaled, and the degree to which they struggle to do so is thought to indicate behavioral disinhibition. Behavioral disinhibition is a form of impulsive action that may be particularly relevant to quitting smoking (in which failing to inhibit smoking behavior in light of a desire or need to quit may have negative emotional, interpersonal, monetary, or health consequences). Disinhibition (the ability to inhibit a response) is positively related to smoking status and heaviness in adults (McClernon et al., 2008; Mitchell, 2004a) and inability to quit smoking in adolescents (Krishnan-Sarin et al., 2007). Few studies report on the reliability of measures of disinhibition, however, and poor

reliability is a problem with some performance measures of cognitive processes in substance users (Ataya et al., 2012). Stop-signal and Conner's Continuous Performance tests of behavioral disinhibition can have good to excellent split-half and test–retest reliability, at least in some populations, such as healthy volunteers and individuals with ADHD (Raz, Bar-Haim, Sadeh, & Dan, 2014; Soreni, Crosbie, Ickowicz, & Schachar, 2009; Weafer, Baggott, de Wit, 2013). The extent to which this holds for smokers during a smoking cessation attempt is not known. Adolescent smokers trying to quit have shown stress-induced within-subject changes in impulsive action (Schepis, McFetridge, Chaplin, Sinha, & Krishnan-Sarin, 2011), so it is possible that impulsive action will vary by smoking deprivation status, as well, such that baseline values convey little about disinhibition risk during quit attempts. The extent to which behavioral disinhibition precessation may serve as a marker for abstinence outcomes in smoking cessation trials among adult smokers is currently unknown.

The current study aims to replicate and extend previous work on facets of impulsiveness in drug dependence by examining relations among: delay discounting as a measure of impulsive choice, behavioral disinhibition as a measure of impulsive action, and success in quitting smoking among adult smokers. Specifically, the study will estimate the reliability, stability, and predictive validity of delay discounting and behavioral disinhibition. The data to be analyzed were collected in a prospective longitudinal study of treatment-seeking adults who smoked daily. Results from this study will assess impulsive choice and impulsive action as candidate markers for relapse risk among smokers engaged in an effort to change.

Method

Participants

Participants were recruited from central New Jersey using mass media, including direct mail, radio, and flyers. Inclusion criteria for this study required participants to be over age 18, read and write in English, be motivated to quit smoking (at least a "6" on a 10-point rating scale ranging from 1 = "*Not at all motivated*" to 10 = "*Extremely motivated*"), smoke at least 10 cigarettes per day for at least 6 months, and have at least 8 ppm carbon monoxide (CO) in their expired breath at baseline. Study exclusion criteria included the following: pregnancy, breastfeeding, or unwillingness to prevent pregnancy for the duration of the study; a history of heart problems including recent heart attack, recent heart surgery, irregular heartbeat, or heart disease; a history of bipolar disorder or psychosis diagnosis; current use of other stop-smoking treatments; past problems using nicotine lozenges; living with someone enrolled in the study; regular use of marijuana, illegal drugs, or other forms of tobacco; or an inability or unwillingness to complete study activities.

Materials and Procedure

Study procedures were approved by an institutional review board. Interested volunteers were screened over the telephone for initial eligibility, and those who were eligible and interested were scheduled for a group orientation session. At the orientation session, participants provided written informed consent and completed questionnaires, CO testing, and training in the use of palmtop computers for data collection. Participants had weekly study visits for 5 weeks and a follow-up phone call 12 weeks after a target quit-smoking day set by investigators. Participants completed measures of impulsive choice and action at three laboratory visits (1 week prequit, on the target quit day, and 3 weeks' postquit). All participants received four individual smoking cessation counseling sessions and a 12-week supply of nicotine lozenges (4 mg for those who smoked within 30 min of waking, 2 mg for those who smoked more than 30 min after waking or could not tolerate the 4 mg lozenge). Participants also carried palmtop computers for 4 weeks (1 week prequit and 3 weeks' postquit) to complete measures of affect, nicotine withdrawal, cigarette cravings, and momentary impulsive choice and impulsive action four times daily.

Participants could earn up to $130 in compensation for attending visits and completing telephone interviews, plus up to $545.40 in bonuses dependent on performance on the measure of impulsive choice (delay discounting) and the measure of impulsive action (a modified version of the Continuous Performance Test-II, CPT-II; Conners, 2004) described below. Some bonuses were tied to choices in delay discounting tasks, such that the first choice in a randomly selected series with a delayed reward value of $100 or less was treated as real. Participants were informed that one of their choices (up to $100) would be selected at random at the end of the task and paid for real to encourage participants to respond according to their true preferences. Participants could earn up to $375 in bonuses in delay discounting tasks ($100 at each of three laboratory visits and $75 by completing a brief delay discounting measure on a palmtop computer). Participants could also earn up to $7.20 in bonuses at each of three laboratory visits ($21.60 total) by earning $0.02 for each correct response on the CPT-II in the laboratory and up to $148.80 by earning $0.02 for each correct response on a 60-trial version of the CPT-II completed on palmtop computers four times per day for 31 days. The mean bonus was $331 (range $27–$512), and participants earned an average of $26 per hr, excluding travel time.

Measures

At baseline, participants completed questionnaires regarding smoking history, cigarette dependence, impulsiveness, and demographics. Only measures pertinent to the current analyses will be discussed below.

Fagerström Test of Cigarette Dependence (FTCD). The FTCD (Fagerström, 2012; Heatherton, Kozlowski, Frecker, & Fagerström, 1991) is a six-item self-report measure of physical dependence on cigarettes. Higher scores (range = 0–10) signify higher rates of physical dependence on nicotine (Fagerström, Heatherton, & Kozlowski, 1990). The internal consistency of the FTCD is fair (Cronbach's alpha = .61; Heatherton et al., 1991). Internal consistency was slightly lower in the current sample (N = 123, Cronbach's alpha = .54).

Barratt Impulsiveness Scale 11 (BIS-11). The BIS-11 is a 30-item self-report measure of impulsiveness (Patton, Stanford, & Barratt, 1995). Items (e.g., "I am self-controlled") are rated on a 4-point scale, with 1 = "*rarely/never*" and 4 = "*almost always/always*." Higher scores indicate greater impulsiveness. The BIS-11 has six primary subscales and three second-order factors (attention

impulsiveness, motor impulsiveness, and nonplanning impulsiveness). The current analyses focused on the second-order factors. The BIS-11 has acceptable internal consistency as indicated by Cronbach's alphas ranging from .79 to .83 (Patton et al., 1995). In the current sample, the BIS-11 total scale had good internal consistency (n = 119, Cronbach's alpha = .85). Internal consistency was fair for the second-order attentional impulsiveness factor (n = 124, Cronbach's alpha = .70), good for nonplanning impulsiveness (n = 123, Cronbach's alpha = .76), but low for motor impulsiveness (n = 121, Cronbach's alpha = .56).

Demographics. Participants reported age, sex, self-identified race, ethnicity, educational attainment, marital status, income, and employment status.

Impulsive choice: Delay discounting task. One week prequit, on the target quit-smoking day, and 3 weeks' postquit, participants completed a computerized delay discounting task programmed with DMDX stimulus control software (Forster & Forster, 2003). Participants were asked to choose which of two monetary rewards, a smaller reward available sooner, or a larger reward available later, they would prefer (e.g., $16 today or $20 in one week). Four larger, later reward magnitudes were tested ($20, $50, $100, $2,500), fully crossed with five delays between rewards (1 day, 1 week, 1 month, 6 months, 2 years). For these choice series, the smaller sooner outcome was always presented as occurring today. To check for immediacy effects (e.g., the extent to which discounting decreases when the smaller, sooner reward is not available immediately), six additional series were run ($20 or $100 delayed reward magnitudes crossed with a delay of 1 day, 1 week, or 1 month). For these choices, the smaller sooner reward was available at a delay of 1, 7, or 30 days. As such, participants were asked to complete 26 series of items, with a maximum of 50 trials per series (M trials per series = 11.71, SD = 4.47). The task took about 20 min. To encourage participants to treat all choices as real, participants were informed at the start of the task that one of their choices up to $100 with a 1-month or shorter delay would be selected at random to be paid.

In each series, the initial value of the smaller, sooner reward presented was selected at random at increments of 4% between zero and the value of the delayed reward. In subsequent trials, upper and lower limits for the next smaller, sooner reward value were adjusted based on participant responses using the double-limit titration algorithm developed by Johnson and Bickel (2002). This algorithm facilitates estimation of indifference points to within 4% of the value of the larger, later reward while also requiring consistency in responding (e.g., a participant must twice indicate that $20 in 1 week is preferable to $12 or more dollars today before the lower limit for the sooner, smaller reward indifferent point is set to $12). A series was terminated when the outer upper and lower limits of the indifference point were within 4% of the delayed reward magnitude. If participants responded inconsistently and the limits did not converge to within 4% of the delayed reward (2.1% of series), the trial ended after 50 items.

Our dependent variable of impulsive choice was calculated using area under the empirical discounting function (Myerson et al., 2001) using only series that converged to within 4% of the delayed reward magnitude (97.9% of series). AUC is a summary measure that represents the area under the curve when the delay between the rewards (normalized as a percent of the longest possible delay) is plotted on the abscissa and the magnitude of the subjective value (the magnitude of the smaller, sooner reward viewed as equivalent to the delayed reward, normalized as a percent of the delayed reward value) is plotted on the ordinate. Area under this curve is computed by summing the area of trapezoids capturing discounting between adjacent delays. The area of each trapezoid is calculated using the formula (Myerson et al., 2001): area = $(D_2 - D_1)[(V_{p1} + V_{p2})/2]$, where D_1 and D_2 are adjacent delays (e.g., 1 week and 1 month) and the V_p values are the subjective value of the reward at the corresponding delays. A larger AUC indicates lower discounting (i.e., lower impulsiveness) because this means that rewards retain their subjective value well over delays, whereas a small AUC reflects greater loss of subjective value with longer delays and, thus, more impulsive choice. AUC addresses skewness in discounting rates and is robust to misspecification of the discounting function (e.g., exponential vs. hyperbolic) because it is an empirical function (Myerson et al., 2001). A separate AUC was computed for each delayed reward magnitude ($20, $50, $100, $2,500) and these were averaged to compute the final AUC measure for each laboratory visit for the current analyses. We considered taking the average across reward magnitudes appropriate because there was a predominantly linear pattern of growth in AUC across increasing reward magnitudes, as described below.

Impulsive action: Behavioral disinhibition. Impulsive action was assessed using a task designed to measure the ability to inhibit a motor response primed by the context. This is a measure of behavioral disinhibition. One week prequit, on the target quit day, and 3 weeks' postquit, participants completed a modified version of the CPT-II (Conners & Staff M.H.S., 2000; Conners, 2004). Participants were asked to press the spacebar every time a letter appeared, except when the letter was an X (10% of the trials). The degree to which participants struggle to do this is captured by the commission error rate (i.e., the percentage of X trials in which participants pressed a key). Each letter was presented for 250 ms with a variable intertrial interval (ITI) of 1, 2, or 4 s. In this modified version of the CPT-II, trials with the three lengths of ITIs were interspersed randomly within blocks of 30 trials, rather than blocked. This change was made to match the version of the task presented in the laboratory to a version presented on palmtop-computers that did not permit blocking of the stimuli by ITI. Participants completed 12 blocks of 30 trials each. In an effort to bolster participant engagement in the task, the task was further modified to provide feedback about errors (both omission and commission errors) and the number of cents earned in each block (at the rate of $0.02 per correct response) after every other block. A 1-min break was provided after the sixth block. This modified CPT-II was programmed using DMDX software (Forster & Forster, 2003).

Commission error rates were computed for each subject at each visit by dividing the number of commission errors made across all blocks by the total number of X trials for which inattention was not a problem (maximum of 36 X trials). These false-positive errors were used to assess behavioral disinhibition, the form of impulsive action of interest in this study. Omission error (failure to respond to non-X trials) rates greater than 5% in any block suggested inattention and blocks in which this occurred were therefore excluded from computation of the commission error rate. These false-negative errors were used only to screen for inattention in the

current study and were not used as an indicator of impulsive action.

Smoking cessation outcomes. Daily tobacco use was assessed using a timeline follow-back calendar method in which participants were asked at each study contact to report on their tobacco, alcohol, and stop-smoking treatment use for each day since the last study contact (Brown et al., 1998). The calendar was completed at every visit and at the 12-week telephone follow-up interview. There were two primary self-reported outcomes: initial cessation (quitting for at least 1 calendar day in the first 2 weeks after the target quit day) and complete 7-day point-prevalence abstinence at the 12-week follow-up. Those who claimed no smoking in the week prior to the 12-week interview were asked to provide evidence of abstinence in the form of a follow-up CO test with less than 8 ppm CO ($n = 23$, 76.7% of the 30 individuals reporting abstinence) or collateral confirmation of abstinence if the person was not able to come in for a CO test ($n = 1$, 3.3% of those reporting abstinence). Prolonged abstinence (no return to smoking for at least 7 days between 2 and 12 weeks' postquit) was treated as a secondary abstinence outcome.

Analysis Plan

Descriptive data were computed for the impulsiveness measures and behavioral outcomes. We computed Pearson Product Moment correlations among BIS-11, AUC, and CPT-II commission error rates to examine associations among facets of impulsiveness. We also computed the internal consistency of AUC across four delayed reward magnitudes and both Guttman split-half and Kuder–Richardson reliability of the no-go trials on the modified CPT-II. We examined test–retest reliability of AUC and CPT-II commission error rates across sessions, both overall, and as a function of smoking status concordance across visits (i.e., to determine whether the measures were significantly less stable if participants quit smoking or relapsed between visits). Hierarchical multiple logistic regression was used to predict each of the smoking abstinence outcomes from the baseline self-report and behavioral measures of impulsiveness with and without adjusting for age, sex, and education. All analyses were conducted using IBM SPSS Statistics 20.0 software (IBM, Corp., Armonk, NY).

Results

Sample Characteristics

Participant flow in the study is shown in Figure 1. Of the 134 enrolled in the study, eight (6.0%) were found to be ineligible because of exclusion criteria not disclosed at initial screenings and were therefore excluded from all analyses. An additional 10 (7.5%) did not complete any postenrollment sessions and therefore did not provide any behavioral impulsiveness data, leaving 116 (86.6%) with some behavioral impulsiveness data. Eligible enrollees who did not complete the first laboratory visit ($n = 10$) did not differ from those who did ($n = 116$) in terms of age, sex, race, cigarette dependence as assessed with the FTCD, or baseline impulsiveness as measured by BIS-11 total or second-order scale scores (all ps > 0.21, all Cohen's ds < 0.33). Those who attrited between the first laboratory visit and the quit day ($n = 10$) also did not differ significantly from those retained through the target quit day ($n = 106$; all ps $> .09$, all Cohen's ds < 0.25), although there were moderate (Cohen's $d = -0.38$) differences in prequit AUC for those retained ($M = 0.61$) versus those lost ($M = 0.53$) and in attentional impulsiveness on the BIS-11 (Cohen's $d = 0.58$) between those retained ($M = 16.01$) versus lost ($M = 18.33$).

Demographic characteristics of the sample are summarized in Table 1. In terms of smoking cessation success, 80 (69.0%) of the 116 subjects with prequit impulsiveness data reported initial cessation (quitting for at least one day in the first 2 weeks posttarget quit day). In intent-to-treat analyses (with all missing cases treated as smoking), point prevalence abstinence (confirmed abstinence in the seven days preceding the 12-week call) was achieved by 21 (18.1%) of participants, whereas prolonged abstinence (no smoking seven days in a row anytime between 2 and 12 weeks' posttarget quit day) was reported by 43 (37.1%).

Visit behavioral impulsiveness data were lost at random because of computer failure for some subjects prequit (choice $n = 2$, action $n = 1$), on the target quit day (choice $n = 2$), and postquit (choice $n = 1$, action $n = 3$).

Impulsive Choice

Descriptive statistics for the impulsive choice and impulsive action measures at baseline (1-week prequit) are shown on the diagonal in Table 2. Mean AUC on the quit day was 0.64 ($SD = 0.28$, $n = 102$) and three weeks post-target-quit-day was 0.68 ($SD = .27$, $n = 98$). In a repeated measures analysis of variance (ANOVA), there was a modest but significant visit effect (Greenhouse-Geisser $F(1.79, 161.17) = 6.91$, $p = .002$, $\eta^2 = .07$), such that AUC increased linearly across visits (reflecting a decline in impulsive choice), $F(1, 90) = 9.53$, $p = .003$, $\eta^2 = .10$, even with listwise deletion (i.e., this did not occur because more impulsive individuals attrited before later visits).

For the AUC measure, there was a significant magnitude effect, such that discounting was greater (and AUC smaller) for smaller delayed reward magnitudes than for larger rewards. Across all three visits (prequit, quit day, postquit), a monotonic and primarily linear pattern of the magnitude effect held (linear components were significant in repeated measures ANOVAs taking into account unequal spacing among reward magnitudes at each visit, $\eta^2 = .27$–$.30$, $p < .001$). As such, we elected to collapse AUC across the four reward magnitudes by taking the mean of the four AUCs at each visit.

There was no significant immediacy effect (i.e., discounting was no greater for series in which the smaller reward was available immediately vs. available after a brief delay) and no significant interaction on the AUC measure between immediacy and reward magnitude at any visit (all ps $> .05$, all η^2s $< .033$). As such, we will not discuss the nonimmediate series further. The summary AUC measure used in subsequent analyses is based on the 20 immediate smaller reward series completed by participants.

Impulsive Action

Prequit, participants made commission errors on 24.5% of "X"-trials (i.e., no-go trials; Table 2). The mean commission error rate was 29.1% ($SD = .301$, $n = 106$) on the target quit day and 25.7% ($SD = .246$, $n = 96$) 3 weeks' postquit. Inattention was rare, with fewer than 1% omission errors at all visits. Within-block omission

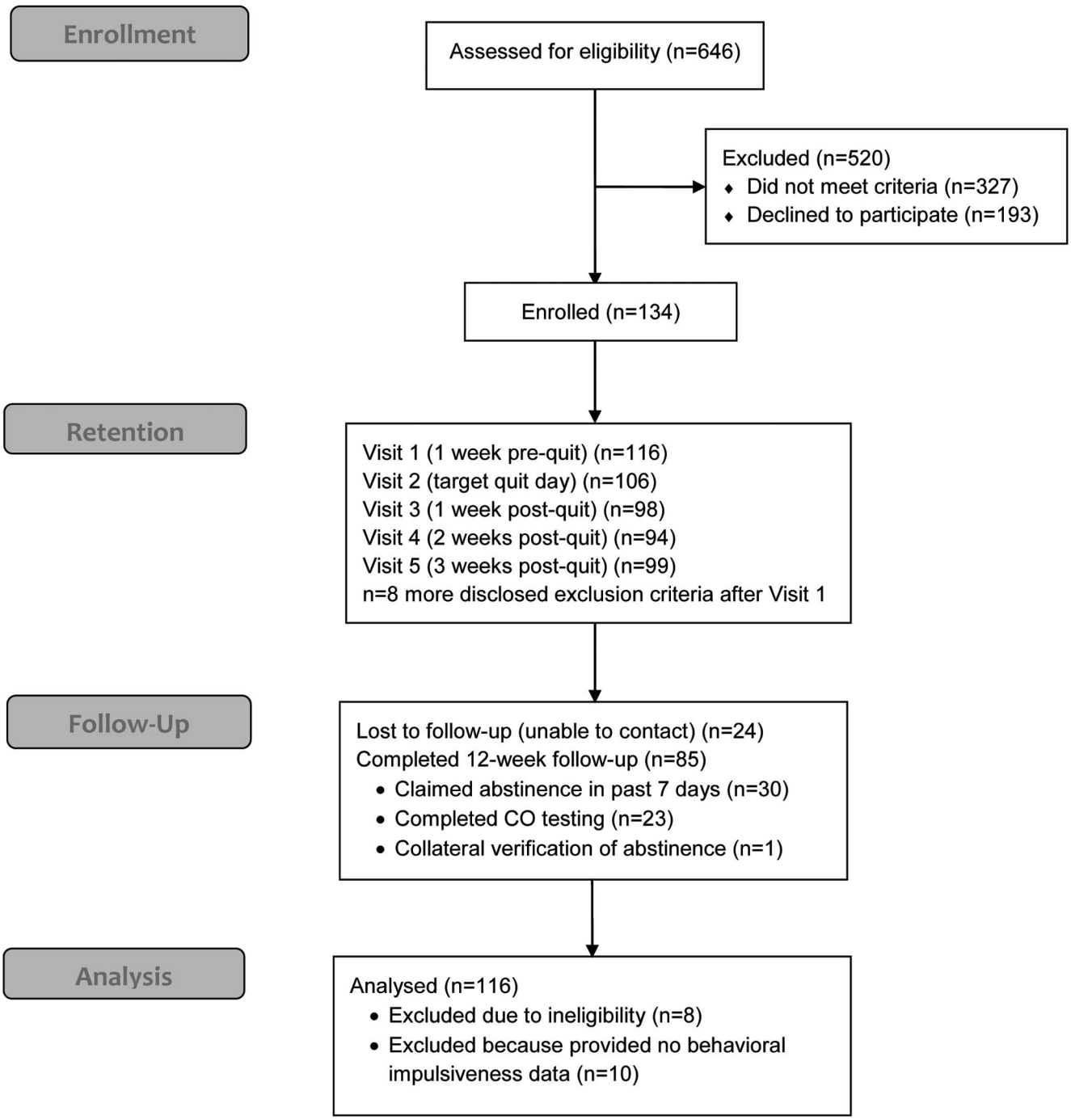

Figure 1. Participant flow diagram.

error rates greater than 5% (3 omissions) occurred on 42 (2.2%) of 1,908 blocks of trials.

There were no significant effects of ITI on either commission or omission error rates (all $ps > .05$, all $\eta^2 < .05$). There was an unexpected significant effect of ITI on reaction time (RT) on correct go trials, Greenhouse-Geisser $F(1.88, 170.58) = 13.58$, $p < .001$, $\eta^2 = .13$, such that RTs were significantly longer for the 2-s ITI trials than for the 1s, $F(1, 91) = 11.73$, $p = .001$, $\eta^2 = .11$, or 4s ITI trials, $F(1, 91) = 25.28$, $p < .001$, $\eta^2 = .22$. This did not appear to be driven by outliers. Reaction times did not differ for the 1s and 4s ITI trials, $F(1, 91) = 1.80$, $p = .18$, $\eta^2 = .02$.

There was a small, significant block effect, Greenhouse-Geisser $F(4.23, 329.74) = 3.37$, $p = .009$, $\eta^2 = .04$, such that error rates decreased linearly, $F(1, 78) = 7.41$, $p = .008$, $\eta^2 = .09$ across the six blocks (i.e., practice effects). There were no significant visit main effects or interactions with ITI or block (all $ps > .05$ and all η^2s $< .03$).

Table 1
Demographic Characteristics of the Analytical Sample (N = 126)

Characteristic	*n*	%
Sex	68	46.0
Male		
Female	58	54.0
Race		
White	83	65.9
African American	30	23.8
Other race	11	8.7
Ethnicity	6	4.8
Hispanic		
Marital status	46	36.5
Married		
Never married	36	28.6
Separated, divorced, or widowed	33	26.2
Not married and cohabitating	11	8.7
Annual household income ($N = 123$)	31	24.6
Less than $20,000		
$20,000 to $49,000	32	25.4
$50,000 to $74,999	26	20.6
$75,000 or more	34	27.0
Highest level of education	34	27.0
High school or less		
Some college	55	43.7
College graduate	37	29.4

	M	*SD*
Age in years	44.71	12.51
Years smoked ($N = 125$)	24.50	12.23
Cigarettes smoked per day	18.89	6.90
Fagerström Test of Cigarette Dependence Score	5.33	1.93
Baseline carbon monoxide	22.49	12.06

Correlations and Reliability

The correlation matrix in Table 2 indicates that impulsive choice and impulsive action measures were not significantly correlated to one another or to Barratt Impulsiveness Scale scores. The Barratt Impulsiveness second-order scales were moderately intercorrelated. The behavioral measures of impulsive choice and action were not significantly associated with sex, minority status, college education, or income (all $|r|$s $< .17$, all ps $> .07$). Increasing age was associated with lower commission error rates on the CPT-II, $r = .30$, $p = .001$.

In terms of reliability (Table 3), both behavioral measures had high Guttman split-half reliability. Kuder–Richardson reliability estimates were very similar to Guttman split-half estimates for CPT data (.88 at visit 1, .92 at visit 2, and .94 at visit 5). Test–retest reliability was assessed for the following intervals: prequit to quit day (1 week), quit day to 3 weeks' postquit (3 weeks), and prequit to 3 weeks post quit (4 weeks). Test–retest reliability was generally high for area under the discounting curve and did not differ significantly when tested under concordant smoking conditions or discordant conditions (as indicated by CO level above or below 10 ppm). Test–retest reliability was lower and less stable for commission error rates on the modified CPT-II. Differences between AUC and CPT-II test-retest reliabilities were significant from prequit to quit day ($z = -2.48$, $p = .01$) and from prequit to postquit ($z = 4.96$, $p < .001$) intervals, but not from quit day to postquit ($z = 1.40$, $p = .16$). Test–retest reliability for the CPT-II did not differ significantly as a function of smoking concordance coded based on CO level (with a 10 ppm cutoff) across visits (Table 3). Defining smoking status based on self-reported abstinence in the past seven days and a CO below 8 ppm in the week before the third visit yielded significant differences in test-retest reliabilities from the quit day (where smoking status was defined based on CO with a cutoff of 10 ppm for abstinence; a higher threshold was used because of the brevity of abstinence at the quit day visit) to postquit, however. Reliability was significantly higher for AUC when individuals had the same smoking status on the quit-day and three weeks later ($r = .917$, $n = 62$) than when smoking status changed between these visits ($r = .798$, $n = 30$, $z = 2.05$, $p < .04$). For the CPT-II, test–retest reliability was significantly lower among those with the same quit day and postquit status ($r = .470$, $n = 61$) than among those whose status changed ($r = .812$, $n = 31$, $z = -3.61$, $p < .001$). This was driven by very low stability among individuals who were smoking at both the quit-day and postquit visit ($r = .371$, $n = 29$), rather than by those abstinent at both points ($r = .735$, $n = 32$, $z = -2.04$, $p < .04$). The degree of change in AUC and CPT-II commission error rates across visits did not correlate significantly for any pair of visits (all rs $< .12$, all ps $> .24$).

Logistic Regression Models

Hierarchical logistic regression analyses were conducted to examine relations between cessation outcomes and self-reported impulsiveness (entered first), impulsive choice and impulsive action (entered second). Models were run with and without control variables (age, sex, education defined as having some college education vs. none, and baseline FTCD scores). Results (Table 4) indicated that initial cessation (the ability to abstain for at least 1 full calendar day in the first 2 weeks of an attempt to quit) was significantly associated with self-reported impulsiveness and im-

Table 2
Bivariate Correlation Matrix of Prequit Impulsiveness Measures, With Means and SDs Shown on the Diagonal

Variable	1	2	3	4	5
1. Impulsive choice: Area under discounting curve ($n = 114$)	.603 (.268)				
2. Impulsive action: CPT commission error rate ($n = 115$)	.022	.245 (.196)			
3. BIS-11 Attentional Impulsiveness ($n = 126$)	.112	−.095	16.183 (4.037)		
4. BIS-11 Motor Impulsiveness ($n = 126$)	.054	.109	.552*	22.500 (4.017)	
5. BIS-11 Nonplanning Impulsiveness ($n = 126$)	−.013	−.135	.539*	.554*	23.413 (5.457)

Note. CPT = Continuous Performance Test; BIS-11 = Barratt Impulsiveness Scale 11.
* $p < .001$.

Table 3
Reliability of Area Under the Discounting Curve (AUC) Measure of Impulsive Choice and Continuous Performance Test (CPT) Commission Error Rate Measure of Impulsive Action

	AUC			CPT		
Variable	Prequit	Quit day	Postquit	Prequit	Quit day	Postquit
Time and smoking concordance						
Prequit	.947 (n = 114)			.881 (n = 110)		
Quit-day concordant	.819 (n = 46)	.966 (n = 102)		.724 (n = 49)	.912 (n = 95)	
Quit-day discordant	.881 (n = 55)			.727 (n = 57)		
Postquit concordant	.731 (n = 37)	.874 (n = 72)	.965 (n = 98)	.749 (n = 36)	.635 (n = 70)	.914 (n = 92)
Postquit discordant	.827 (n = 60)	.918 (n = 20)		.675 (n = 60)	.553 (n = 22)	

Note. Cronbach's alpha for the four delayed reward magnitude areas under the curve are shown on the diagonal of the AUC matrix. Guttman split half reliability of the CPT is shown on the diagonal. Test–retest reliability across the three assessment occasions (1 week prequit, on the target quit day, and 3 weeks posttarget quit day) are shown on the off-diagonal, with separate estimates for those whose smoking status was concordant or discordant across two visits (with smoking status at each visit coded based on carbon monoxide with a 10 part per million cutoff).

pulsive action. Those who made all possible commission errors had only 6% of the log odds of initial cessation as those who made no commission errors. Individuals who reported greater attentional impulsiveness on the BIS-11 were also less likely to quit initially (with a 14% reduction in the log odds of quitting for each additional point on the BIS-11 attentional scale). Those who reported greater motor impulsiveness, in contrast, had increased log odds of quitting initially (18% for each point on the BIS-11 scale). Although there was a large odds ratio (4.0) for AUC, impulsive choice was not significantly related to initial cessation in the full intent-to-treat sample.

In a model predicting 7-day point-prevalence abstinence at 12 weeks, in contrast, prequit AUC significantly predicted abstinence, such that reduced discounting (and increased AUC) was positively associated with abstinence. No other impulsiveness or control variables were associated with point-prevalence abstinence.

In terms of prolonged abstinence (no return to seven days of smoking between weeks two and 12), only impulsive action was significantly predictive, such that higher error rates on the CPT-II were associated with lower log odds of abstinence. This effect was reduced to nonsignificance in models controlling for age, sex, minority status, college education, and FTCD, none of which were significantly related to any abstinence outcome. Although none of the covariates was significantly associated with prolonged abstinence, they shared some variance with commission error rates (particularly age, which was moderately negatively correlated with commission error rate, $r = -.30$, $p = .001$).

If analyses were restricted to only those (n = 106) who were retained through the target quit day (i.e., those who attempted to quit), AUC was significantly related to both initial cessation (B = 1.67, SE = .85, odds ratio [OR] = 5.32, 95% confidence interval [CI] = 1.00–28.21) and 3-month point-prevalence abstinence (B = 2.21, SE = 1.04, OR = 9.07, 95% CI = 1.19–68.93), whereas the CPT-II (B = −2.35, SE = 1.29, OR = 0.10, 95% CI = 0.08–1.18 for initial cessation, and B = −0.74, SE = 1.44, OR = 0.48, 95% CI = 0.03–1.18 for 3-month point-prevalence abstinence) and attentional impulsiveness (B = −0.15, SE = 0.08, OR = 0.86, 95% CI = 0.73–8.01 for initial cessation and B = −0.11, SE = 0.09, OR = 0.90, 95% CI = 0.76–1.07 for 3-month point-prevalence abstinence) were not.

Discussion

The aim of the present study was to gather information about the reliability, stability, and concurrent and predictive validity of be-

Table 4
Results of Multiple Logistic Regression Models of Cessation Outcomes

	Initial cessation (69.9% quit at least 1 day in first 2 weeks)		12-week point prevalence abstinence (18.6% abstinent)		2- to 12-week prolonged abstinence (38.1% abstinent)	
Variable (N = 113)	B (SE)	OR (95% CI)	B (SE)	OR (95% CI)	B (SE)	OR (95% CI)
Impulsive choice: Area under discounting curve	1.386 (.829)	4.000 (.788–20.306)	2.536 (1.115)	12.634* (1.421–112.307)	1.236 (.788)	3.443 (.735–16.120)
Impulsive action: CPT commission error rate	−2.900 (1.170)	.055* (.006−.545)	−1.670 (1.407)	.188 (.012–2.966)	−2.315 (1.152)	.099*[a] (.010–.944)
BIS 11: Attentional impulsiveness	−.152 (.073)	.859* (.744–.991)	−.118 (.087)	.889 (.749–1.054)	−.079 (.067)	.924 (.810–1.054)
BIS 11: Motor impulsiveness	.163 (.076)	1.176* (1.014–1.365)	.118 (.085)	1.125 (.953–1.327)	.031 (.068)	1.032 (.903–1.179)
BIS 11: Nonplanning impulsiveness	−.055 (.051)	.947 (.857–1.046)	−.014 (.060)	.986 (.877–1.108)	−.041 (.048)	.959 (.873–1.055)

Note. OR = odds ratio; CI = confidence interval; CPT = Continuous Performance Test; BIS 11= Barratt Impulsiveness Scale 11.
[a] Reduced to nonsignificance ($p > .05$) if model includes: age, sex, minority status, college education (1 = *some*, 0 = *none*), and FTCD, none of which were significantly related to any abstinence outcome.
* $p < .05$.

havioral measures of impulsive choice and action to evaluate their potential to serve as markers for smoking cessation success. Results indicated that the delay discounting task was a reliable measure of impulsive choice that was largely stable over time and smoking status, independent of other facets of impulsiveness, and predictive of success in quitting above and beyond self-reported impulsiveness. In addition, both impulsive action, as assessed by commission error rate on a modified continuous performance test, and self-reported impulsiveness were related to the ability to establish initial abstinence at the outset of a quit attempt, but were not robustly related to later abstinence. Impulsive action and self-reported impulsiveness relations with abstinence were not robust, however, and did not persist in analyses restricted to participants retained through the target quit day. Taken together, these results suggest that impulsive choice may be a promising marker of the ability to enact lasting change, whereas self-reported impulsiveness and impulsive action may be markers of the ability to initiate change in the near-term. The results also highlight the distinctiveness of the varied measures of impulsiveness in terms of associations, stability, and predictive validity.

The data from the current study support the conceptualization of impulsive choice and impulsive action as separate components of impulsiveness, both of which have relevance to drug use (de Wit, 2009; Perry & Carroll, 2008; Weafer et al., 2013). As in earlier studies of healthy young adults (as reviewed by de Wit, 2009), we found that impulsive choice, impulsive action, and self-reported impulsiveness were not significantly associated with one another in heavy daily smokers. This was not because of low reliability of the measures. The AUC measure of impulsive choice had excellent internal consistency. The commission error rate measure had excellent Guttman split-half and Kuder–Richardson reliability. The self-report measures of impulsiveness also had good internal consistency, with the exception of the motor impulsiveness scale (Cronbach's alpha = 0.56, which is similar to that reported in other studies, Stanford et al., 2009). Instead, it appears as though these measures are capturing separate forms of impulsiveness, or in the case of the self-report measure, perhaps awareness of specific forms of impulsiveness, that need not hang together in individuals. Others (Dougherty, Mathias, & Marsh, 2003; Stanford et al., 2009) have interpreted the lack of association between BIS scores and behavioral measures of impulsiveness as evidence that the BIS measures more stable aspects of personality or subjective experience, whereas the behavioral measures are more state-dependent. The BIS-11 has shown great stability across repeated administrations in past research but delay discounting has shown similar stability, at least in similar testing conditions (Weafer et al., 2013).

The distinctiveness of impulsive choice and impulsive action was further supported by the differential stability of impulsive choice and impulsive action over repeated administrations. Whereas impulsive choice as measure by AUC was fairly stable across time and smoking states (with test–retest reliability exceeding 0.73 at every interval), impulsive action as measured by commission error rate on the CPT-II was less stable, with test–retest reliability below 0.75 from prequit to postquit and from quit day to postquit. This accords with past research in healthy young adults suggesting that delay discounting is fairly stable over three months (Ohmura et al., 2006), and more recent work showing that the AUC is highly stable (test–retest reliability 0.89) over repeated administrations roughly 10 days apart, whereas CPT commission error rates were more moderately correlated across visits (test–retest reliability 0.73; Weafer et al., 2013). This difference may reflect core differences in these facets of impulsiveness (e.g., behavioral disinhibition may be more influenced by states such as fatigue or distraction than impulsive choice or beliefs about the self) or aspects of the measurement approach (e.g., an insufficient number of "no go" trials to achieve optimal reliability, although reliability was quite high in the current sample). Test–retest reliability was greater with continuity in smoking status from the quit day to week-long abstinence postquit for AUC, but was high (above .80) in both cases. For the CPT-II, test–retest reliability was unexpectedly lower when there was continuity in quit day to 3-week postquit smoking status (particularly among those smoking at both visits), than when there was discontinuity. The low test–retest reliability of the CPT-II among people who continued smoking postquit might reflect flagging motivation or effort in the face of difficulty quitting. Overall, the results support the notion that the CPT-II is less stable than the AUC in smokers trying to quit.

In terms of predictive validity, all the measures of impulsiveness examined in this study were predictive of abstinence at some point in the cessation process. In the full sample, initial cessation (the ability to abstain for at least one day in the first two weeks of a quit attempt) was more likely among those with lower commission error rates, and therefore greater behavioral inhibition. In analyses restricted to those who made quit attempts (i.e., those retained through the quit date), impulsive choice was associated with initial cessation, while impulsive action was not. Thus, the relation between impulsive action and initial cessation was not robust across these analyses, despite the fact that the 10 people lost in the week before the quit day did not differ significantly or substantially in impulsive action from those retained. Initial cessation was also associated with lower attentional impulsiveness on the BIS-11, but this effect was also not robust and was nonsignificant among those retained through the quit day. Loss of power or variability may also have accounted for this lack of robustness. Surprisingly, cessation was positively related to reports of motor impulsiveness on the BIS-11. This unexpected association may be spurious, particularly given the low reliability of the motor impulsiveness scale and its lack of significance in the analysis of participants retained through the quit day. Alternatively, this finding may reflect a protective effect of greater awareness of one's tendency to behave impulsively at the outset of a change attempt. Individuals who recognize their tendencies to act without thinking and choose to attempt to quit, despite this knowledge or belief, may be highly motivated and may work particularly hard to establish abstinence. Such awareness does not appear to be related to longer-lasting success in quitting smoking, however, as the estimated odds ratio for motor impulsiveness shrinks to nonsignificance in models of abstinence at 12 weeks.

Whereas impulsive action was significantly associated with difficulty establishing initial abstinence, impulsive choice appeared to be a better marker of 7-day point-prevalence abstinence at 12 weeks' postquit day. This is consistent with animal research indicating that rats high in impulsive action (assessed in a five-choice serial RT task) were more likely to maintain self-administration (i.e., not achieve cessation), whereas rats high in impulsive choice (assessed with a delayed-reward task) were more likely to relapse after cessation than were other rats (Diergaarde et al., 2008). The differ-

ential relations of impulsive action and impulsive choice with cessation versus relapse may reflect important differences in the challenges in specific phases of the cessation process. Impulsive action is likely to be of particular importance at the outset of quitting when motivation is high (perhaps even high enough to dampen impulsive choice), but behavioral responses linked to smoking (e.g., reaching for a cigarette) are highly dominant and those associated with alternatives (e.g., reaching for a stick of gum) are weak and not yet linked with the triggers that elicit smoking responses. Over time, however, impulsive action may fade in importance as alternative response inclinations gain strength and smoking responses weaken, while impulsive choice may grow in importance as motivation to quit waivers (e.g., the costs of quitting may loom larger and the benefits of quitting more remote as withdrawal and craving develop, thus making smoking more attractive).

Taken together with the differential stability of impulsive choice and action and the lack of robustness in relations between initial cessation and impulsive action, these findings suggest that impulsive choice may be a better candidate marker for difficulty quitting smoking than impulsive action (Ohmura et al., 2006). In addition, it does not appear that self-reported impulsiveness assessed with the BIS-11 captures risk for long-term continued smoking, as these effects were nonsignificant and the odds ratios were modest in models of abstinence at 12-weeks. Instead, impulsive choice was predictive of verified point-prevalence abstinence at 12-weeks, above and beyond self-reported impulsiveness and impulsive action.

Conclusions regarding the reliability and validity of components of impulsiveness should be tempered by the following considerations. First, the sample of smokers enrolled in this study may not be representative of the general population of smokers attempting to quit, as the volunteers in this study agreed to participate in a demanding longitudinal study involving intensive ecological momentary assessment. In addition, no-cost treatment and remuneration were offered, which may affect sample representativeness. A modified version of the CPT-II was used to ensure comparability with a brief version administered by palmtop computers in this sample. Despite the modifications made to the CPT-II (interspersing trials of varying inter-trial-intervals and providing feedback on response time, accuracy, and incentives earned after each block), estimates of test–retest reliability and concurrent validity were highly similar to previous research using the CPT-II. Third, we collapsed over small but significant reward magnitude effects in the AUC and block effects in the CPT-II to compute summary AUC and commission error rate variables for each visit. This may have obscured specific effects dependent on reward magnitude or block. We were interested in identifying potential markers robust to these methodological factors, and so chose to collapse across these effects.

Conclusions

The results from the current study add to the growing literature on the reliability, stability, and predictive validity of measures of impulsiveness among substance users. This study highlights the distinctiveness among components of impulsiveness. The current results suggest that area-under-the-discounting-curve may be a useful marker of continued smoking, as it is reliable, stable, and significantly predictive of 12-week abstinence in adult daily smokers seeking to quit.

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