

Catecholamine levels and delay discounting forecast drug use among African American youths

Gene H. Brody¹, Tianyi Yu¹, James MacKillop², Gregory E. Miller^{3,4}, Edith Chen^{3,4}, Ezemenari M. Obasi⁵ & Steven R. H. Beach⁶

Center for Family Research, University of Georgia, Athens, GA, USA,¹ Department of Psychology, University of Georgia, Athens, GA, USA,² Department of Psychology, Northwestern University, Evanston, IL, USA,³ Institute for Policy Research, Northwestern University, Evanston, IL, USA,⁴ Department of Educational Psychology, University of Houston, Houston, TX, USA⁵ and Owens Institute for Behavioral Research, University of Georgia, Athens, GA, USA⁶

ABSTRACT

Aims To test hypotheses about the contributions of the catecholamines epinephrine and norepinephrine [which serve as biological markers of life stress through sympathetic nervous system (SNS) activation], delay discounting and their interaction to the prediction of drug use among young African American adults. **Design** A 1-year prospective study that involved assessment of SNS activity and collection of self-report data involving delay discounting and drug use. **Setting** Rural communities in the southeastern United States. **Participants** A total of 456 African Americans who were 19 years of age at the beginning of the study. **Measurements** At age 19, participants provided overnight urine voids that were assayed for epinephrine and norepinephrine. Participants were also assessed for hyperbolic temporal discounting functions (k) and drug use. At age 20, the participants again reported their drug use. **Findings** Linear regression analyses revealed that (i) catecholamine levels at age 19 forecast increases in drug use [$B = 0.087$, $P < 0.01$, 95% confidence interval (CI) = 0.025, 0.148] and (ii) among young men, catecholamine levels interacted positively with delay discounting to forecast increases in drug use (simple slope = 0.113, $P < 0.001$, 95% CI = 0.074, 0.152). **Conclusions** Higher urinary catecholamine concentrations in their adulthood predict higher levels of drug use a year later among young African American men in the United States who engage in high, but not low, levels of delay discounting.

Keywords African Americans, catecholamines, delay discounting, drug use, epinephrine, norepinephrine, rural areas, stress, sympathetic nervous system, young adults.

Correspondence to: Gene H. Brody, Center for Family Research, University of Georgia, 1095 College Station Road, Athens, GA 30602-4527, USA. E-mail: gbrody@uga.edu

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INTRODUCTION

In this study, hypotheses were tested about the contributions of the catecholamines, epinephrine and norepinephrine, which serve as biological markers of exposure to life stress through activation of the sympathetic nervous system (SNS), and delay discounting (DD), a behavioral characteristic that increases vulnerability to drug use and abuse. Particular attention was given to the interaction of catecholamines and DD in the prediction of drug use among 456 young African American adults. Using a 1-year prospective design, we tested the hypothesis that catecholamine levels assayed at age 19 would forecast drug use at age 20 among young men who engaged in high levels of DD. In the following sections, we review the literature that supports these hypotheses.

Life stress is a demonstrated risk factor for youths' high-intensity drug use and other risk behaviors because it precipitates emotional distress and perceptions of limited efficacy and control [1]. Cross-sectional surveys, prospective surveys and experience sampling studies with youth in the United States and other countries have found initiation and escalation of drug use to be positively associated with life stress [2]. Life stress also has a demonstrated durable influence on the SNS, resulting in greater tonic release of its end-products, epinephrine and norepinephrine, in children [3], adolescents [2] and adults [4]. Thus, we hypothesized that heightened levels of catecholamines, a biological embodiment of life stress, would forecast youth drug use from ages 19 to 20 years.

The second hypothesis tested in this study proposed that DD, the tendency to choose smaller immediate

rewards over larger postponed rewards, will interact with catecholamine levels to predict drug use. A preference for immediate rewards is consistent with an affinity for prompt gratification and a diminished ability to resist temptations such as alcohol, tobacco, drugs and overeating [5]. A recent meta-analysis of studies examining the relation between DD and drug use revealed significantly elevated DD with a medium effect size ($d = 0.59$) [6]. Fields *et al.* [7] also found that DD serves as a mediator linking stress to smoking in young adults. Research on DD to date has not focused on its relation to drug use in the context of stress indicators (i.e. a main-effect model) and has not determined whether DD processes are most relevant for youth experiencing high levels of stress (i.e. an interaction model). The interaction model comprises both risk-enhancing effects (i.e. high levels of DD increasing the impact of SNS activation on drug use) and potential protective effects (i.e. low levels of DD reducing the impact of SNS activation on drug use). This study proposed that high levels of DD would enhance the contributions of SNS activation to drug use, and that low levels of DD would buffer youth from drug use when SNS activation was high.

The third hypothesis stipulated that the postulated catecholamine level \times DD interaction would be specific to young men, not emerging for young women. This hypothesis was based on epidemiological data indicating that: (i) male youth tend to externalize the effects of high life stress and female youth tend to internalize such effects, with these patterns possibly linked to gender differences in drug use [8]; (ii) male youth are more impulsive than are female youth [9]; and (iii) male youth use drugs more frequently and at greater quantities during adolescence and young adulthood than do female youth [10].

The present research

Longitudinal data were collected across 1 year during the transition to young adulthood, a period of increased drug use for rural African Americans [2,11]. Participants provided drug use data at ages 19 and 20 years. Overnight urine voids from which epinephrine and norepinephrine were assayed were collected at age 19, and data on DD were collected at age 20. We predicted that high catecholamine levels would forecast drug use among young men who manifested high, but not low, levels of DD.

METHODS

Participants

The sample was taken from a study of African American youth whose mean age was 11.2 years at the first assess-

ment and 20.0 years at the last assessment. Data were collected annually. At the first assessment, 667 families were selected randomly from lists that schools provided of 5th-grade students [12]. The youth resided in nine rural counties in the state of Georgia in the United States. From a sample of 561 at the age 19 data collection (a retention rate of 84%), 500 youth were selected randomly to participate in the age 19 and 20 assessments described previously. Financial constraints associated with the overnight collection and the assay of urine necessitated the selection of a random subsample. Of the subsample of 500, 489 agreed to participate. Of the 489 participants for whom overnight urine voids were collected at age 19, 456 agreed to participate in the age 20 data collection wave. These 456 participants constituted the sample in the present study. Comparisons, using independent *t*-tests and χ^2 tests, of the 456 youth who provided data at age 20 with the 33 who did not revealed no differences on any demographic or study variable.

Participants' mean age was 19.2 years [standard deviation (SD) = 0.65] at the first assessment and 20.0 (SD = 0.69) years at the second assessment. Of the youth in the sample, 54% were female. The participants resided in nine rural counties in Georgia, in small towns and communities in which poverty rates are among the highest in the nation and unemployment rates are above the national average [13]. At the first assessment, 45.2% lived below federal poverty standards with a median family income per month of \$1700; at the second assessment, the proportion was 46.5% with a median income of \$1834.

Study procedure and outcome measures

All data were collected in participants' homes using a standardized protocol. Written informed consent was obtained from care-givers and youth. At each wave of data collection, two African American field researchers conducted one visit to collect self-report data. The field researchers received 8 hours of training on data collection protocols. The field researchers interviewed the primary care-giver and the target youth separately and privately, with no other family members present or able to overhear the conversation. Primary care-givers suggested a place that was private and out of others' view. Catecholamines, drug use and socio-economic status were assessed when youth were 19; DD and drug use were measured when they were 20.

Control variables

Six dichotomous variables measured at the age 19 data collection formed a socio-economic status index. Primary care-givers provided this information. A score of 1 was assigned to each of the following: family poverty based on

federal guidelines, care-giver unemployment, receipt of government financial assistance, care-giver single parenthood, care-giver education level less than high school graduation and care-giver-reported inadequacy of family income. The scores were summed to form the index. Gender was dummy coded; male = 1 ($n = 206$) and female = 0 ($n = 250$). The socio-economic status index was controlled in all analyses because this variable is associated with catecholamine levels and drug use [14]. Gender was controlled in the analysis of the main effects because it is consistently linked with drug use [2].

Young adult catecholamines

The protocol for measuring catecholamines when youth were 19 years of age was based on procedures that Evans [3] and Brody *et al.* [15] developed for field studies involving children and adolescents. Participants collected their overnight (8 p.m.–8 a.m.) urine voids. All urine voided during this time was stored on ice in a container with metabisulfite as a preservative and taken to a laboratory at the University of Georgia, where total volume was recorded, and four 10-ml samples were extracted randomly and deep-frozen at -80°C until subsequent assays were completed. The pH of two of these samples was adjusted to 3 to inhibit oxidation of catecholamines. The frozen urine was delivered to the Emory University Hospital medical laboratory in Atlanta, Georgia, for assaying. Participants received training on the protocol that included procedures for collecting urine when they awoke in the morning. Epinephrine and norepinephrine were assayed with high-pressure liquid chromatography with electrochemical detection [16]. For epinephrine, mean intra-assay coefficients of variation (CV) for non-sequential duplicates are 27.1% (<40 pg/ml), 13.5% (40–80 pg/ml) and 9.6% (>80 pg/ml); pooled samples mathematical average inter-assay CV for 60–140 pg/ml is 16.3%; and blanks read 7.0 ± 14.5 (SD) pg/ml. For norepinephrine, mean intra-assay CVs for non-sequential duplicates are 6.6% (<400 pg/ml), 6.5% (400–800 pg/ml) and 7.1% (>800 pg/ml); pooled mean inter-assay CV for 300–500 pg/ml is 10.3%; and blanks read 6.0 ± 10.3 (SD) pg/ml. Creatinine assay via Jaffe rate methods controlled for body size differences and incomplete urine voiding [17]. SNS catecholamine scores were calculated by summing standardized scores for overnight epinephrine and norepinephrine ($r = 0.532$, $P < 0.001$).

Delay discounting

DD was assessed at age 20 using the Monetary Choice Questionnaire (MCQ) [18], which has been used widely for examining impulsive discounting and addictive behavior [6]. This 27-item measure poses dichotomous choices between smaller immediate rewards and larger

delayed rewards (e.g. \$54 today versus \$80 in 30 days). Hyperbolic temporal discounting functions (k) are inferred by examining patterns of responding and determining a k value that is most consistent with the observed choices [18]. Unlike a permuted task in which a large array of possible discounted values choices are presented over several delay periods, the MCQ does not generate individual points of indifference. Nine items are used to assess DD for small, medium and large rewards, respectively. To avoid Type I error rate inflation, however, only large reward discounting was analyzed. Small and medium reward discounting were highly intercorrelated with large reward discounting ($r_s = 0.74$ – 0.88 , $P < 0.001$). In addition, decision-making for large rewards exhibited the most variability, with definitely more participants exhibiting maximum levels of discounting for small and medium magnitude rewards. The discounting functions were positively skewed, which is common [6]. The functions were transformed using a \log_{10} transformation, which substantially improved the distribution.

Young adult drug use

When youth were aged 19 and 20 years, they reported their past month use of cigarettes, alcohol and marijuana on a widely used instrument from the Monitoring the Future Study [19]. Youth were asked how often during the past month they had engaged in each of these forms of drug use. A seven-point response set ranging from 'not at all' to 'more than two packs a day' was used for cigarette smoking; a six-point scale ranging from 'none to 20 or more times' was used for alcohol and marijuana use. Responses to these four items were summed to form a drug use composite, a procedure that is consistent with our own and others' prior research [20,21]. Because drug use rates were low and skewed positively, the variables were log-transformed; this improved the distribution. Alphas were 0.71 at age 19 and 0.70 at age 20.

Plan of analysis for the study hypothesis

Hierarchical regression analysis was used to test the study hypotheses because this statistical strategy conforms to best practices for testing moderational hypotheses [22]. Specifically, moderational hypotheses are evaluated through tests of an interaction term between a main effect (catecholamine levels) and a moderator (DD) to predict drug use. Three regression models were executed on drug use at age 20. In each model, family socio-economic status and youths' drug use at age 19 were entered first to be controlled.

The first model was designed to examine the main effects of gender, catecholamine levels and DD. The second model examined the two-way interaction between

catecholamine levels and DD. The third model estimated the contributions of the respective two- and three-way interactions among catecholamine levels, DD and gender. Catecholamine levels and DD scores were centered before the interaction terms were calculated. Effect sizes are reported as coefficients, and a conventional Type I error rate of $P < 0.05$ was used. In addition, a collinearity test based on a variance inflation factor (VIF) and tolerance was conducted to examine multicollinearity among the predictors. A tolerance value less than 0.1 or a VIF value greater than 10 indicates significant multicollinearity [23]. Results showed that none of the predictors used in the regression analyses, including the two-way interaction terms and the three-way interaction term, evinced any indication of multicollinearity: VIF ranged from 1.02 to 1.87 and tolerance ranged from 0.61 to 0.98. Given the group-randomized design of the study (randomization on the county level), the regression analyses also included an adjustment for clustering within counties using the COMPLEX analysis option in Mplus 7.11 [24]. This option accounts for non-independence in the data by calculating adjusted standard errors that are robust to hierarchical sampling [25].

RESULTS

Preliminary analyses

Table 1 presents descriptive statistics along with bivariate correlations separately for men and women. We conducted $2(\text{time-points}) \times 2(\text{gender})$ repeated-measures analyses of variance (ANOVAs), with time as a repeated factor and gender as a between-group factor, with drug use as a dependent variable. The results revealed a significant time effect ($F_{(1, 454)} = 3.961, P < 0.05$) and a significant gender effect ($F_{(1, 454)} = 20.29, P < 0.001$). Youth, in general, increased their drug use from age 19 [mean = 0.658, 95% confidence interval (CI) = 0.592, 0.725] to age 20 (mean = 0.723, 95% CI = 0.654, 0.793). Young men (mean = 0.828, 95% CI = 0.739, 0.917) engaged in more drug use than did young women

(mean = 0.553, 95% CI = 0.472, 0.634). No significant time \times gender interactive effects on drug use emerged, $F_{(1, 454)} = 0.006, P = \text{not significant (NS)}$. As predicted, catecholamine levels at age 19 were associated with drug use at both age 19 and age 20 for young men but not for young women.

Test of the study hypotheses

The results of the linear regression models are presented in Table 2. In all models, the family socio-economic status index and youth drug use at age 19 were controlled. The first model (model 1), presented in Table 2, was designed to identify the main effects of catecholamine levels, DD and gender. Results indicated that catecholamine levels at age 19 significantly predicted drug use at age 20 [$B = 0.038$, standard error (SE) = 0.013, $\beta = 0.087, P < 0.01, 95\% \text{ CI} = 0.025, 0.148$] beyond the effects of DD, gender, socio-economic status and drug use at age 19.

The second and third models in Table 2 were designed to determine whether catecholamine levels interacted with DD (model 2) or whether a three-way interaction among catecholamine levels, DD and gender would best characterize the data (model 3). An interaction between catecholamine levels and DD did not emerge for the total sample (Table 2, model 2), but did emerge for the three-way interaction involving gender (Table 2, model 3, $B = 0.102, SE = 0.022, \beta = 0.115, P < 0.001, 95\% \text{ CI} = 0.057, 0.173$). To test further the study hypotheses, additional analyses were conducted that examined the two-way interaction between catecholamine levels and DD separately for men and women (see Table 3). The results revealed a significant two-way interaction for men ($B = 0.074, SE = 0.024, \beta = 0.113, P < 0.01, 95\% \text{ CI} = 0.036, 0.191$) but not for women ($B = -0.028, SE = 0.019, \beta = -0.063, P = \text{NS}, 95\% \text{ CI} = -0.141, 0.016$). To interpret the finding for young men, we plotted estimated drug use at low (1 SD below the mean; -1 SD) and high (1 SD above the mean; $+1 \text{ SD}$) levels of catecholamines and DD; the results are presented in

Table 1 Descriptive statistics and correlations among study variables for male and female youth.^a

Variables	1	2	3	4	5	Male youth		Female youth	
						Mean	SD	Mean	SD
1. SES index (age 19)	–	–0.126	0.096	–0.045	–0.121	3.015	1.706	3.008	1.608
2. Drug use (age 19)	0.015	–	0.083	0.000	0.533***	0.795	0.821	0.522	0.621
3. Catecholamines (age 19)	–0.091	0.155*	–	–0.009	0.102	0.134	1.732	–0.113	1.739
4. DD (age 20)	0.111	0.071	0.064	–	0.069	–1.474	0.788	–1.580	0.928
5. Drug use (age 20)	0.025	0.579***	0.206**	0.054	–	0.862	0.836	0.584	0.674

DD = delay discounting. ^aCorrelations for male youth are presented below the diagonal, and correlations for female youth are presented above the diagonal. SD = standard deviation; SES = socio-economic status. * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 2 Catecholamines, delay discounting and gender as predictors of drug use at age 20 (n = 456).

Predictors	Drug use (age 20)								
	Model 1			Model 2			Model 3		
	B	SE	β	B	SE	β	B	SE	β
1. SES index (age 19)	-0.009	0.015	-0.019	-0.009	0.015	-0.018	-0.006	0.016	-0.013
2. Drug use (age 19)	0.572	0.034	0.547***	0.572	0.033	0.547***	0.572	0.032	0.547***
3. Gender (male)	0.109	0.065	0.071	0.107	0.064	0.070	0.103	0.065	0.067
4. Catecholamines (age 19)	0.038	0.013	0.087**	0.037	0.014	0.085**	0.024	0.013	0.054
5. DD (age 20)	0.036	0.041	0.055	0.037	0.049	0.042	0.047	0.038	0.053
6. Catecholamines \times DD				0.011	0.022	0.020	-0.028	0.019	-0.052
7. Catecholamines \times gender							0.027	0.026	0.041
8. DD \times gender							-0.028	0.092	-0.019
9. Catecholamines \times DD \times gender							0.102	0.022	0.115***

DD = delay discounting; SES = socio-economic status; SE = standard error. ** $P < 0.01$; *** $P < 0.001$.

Table 3 Catecholamines and delay discounting as predictors of drug use at age 20 for male and female youth.

Predictors	Drug use					
	Male youth (n = 206)			Female youth (n = 250)		
	B	SE	β	B	SE	β
1. Socio-economic risk (age 19)	0.014	0.028	0.028	-0.025	0.019	-0.059
2. Drug use (age 19)	0.570	0.071	0.560***	0.568	0.053	0.523***
3. Catecholamines	0.055	0.027	0.115*	0.025	0.013	0.065
4. DD	0.021	0.093	0.020	0.046	0.039	0.063
5. Catecholamines \times DD	0.074	0.024	0.113*	-0.028	0.019	-0.063

DD = delay discounting; SE = standard error. * $P < 0.05$; *** $P < 0.001$.

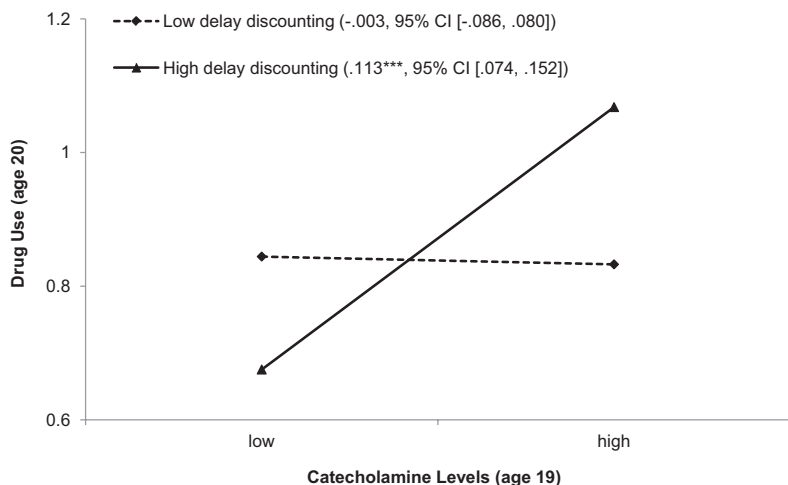


Figure 1 Male youths' drug use as a function of catecholamine levels and delay discounting, with family socio-economic status (SES) index and drug use at age 19 controlled, presented as regression lines for different levels of delay discounting [low: 1 standard deviation (SD) below the mean; high: 1 SD above the mean]. Numbers in parentheses refer to simple slopes with 95% confidence intervals. *** $P < 0.001$

Fig. 1. Consistent with the study hypothesis, the data plots indicate that young men with high catecholamine levels at age 19 reported high levels of drug use at age 20, with drug use at age 19 controlled, when they evinced high DD (simple-slope = 0.113, SE = 0.020, $P < 0.001$,

95% CI = 0.074, 0.152). The data also demonstrated clearly that, for young men with low DD, high levels of catecholamines at age 19 did not forecast high levels of drug use at age 20 (simple-slope = -0.003, SE = 0.042, $P = NS$, 95% CI = -0.086, 0.080).

DISCUSSION

This research was designed to test the prediction that catecholamine levels would forecast drug use among young men who engaged in high levels of DD. Hierarchical multiple regression analyses showed that (i) catecholamine levels at age 19 forecast drug use at age 20, with age 19 drug use controlled; (ii) a catecholamine level \times DD level \times gender interaction indicated that, for male youth, drug use was highest when both catecholamine levels and DD levels were high, a risk-promoting effect of DD; and (iii) the catecholamine \times DD \times gender interaction also indicated that drug use among young men was low when catecholamine levels were high and DD levels were low, a protective effect of DD.

Our working hypothesis was that the impact of SNS activation on drug use would depend upon a preference for immediate rewards as measured by DD rates, particularly for male youth. The behavioral mechanisms for the risk-enhancing effects of SNS activation on drug use are currently unknown. We conjecture that high levels of catecholamines, along with a propensity for immediate gratification, have implications for the ways in which young men with this biological and behavioral profile use drugs to cope with stress. Baumeister & Scher [26] advanced a parsimonious explanation for impulsive tendencies among people who experience life stress. Such people desire the quickest possible escape from life stress and the negative arousal that accompanies it; therefore, they focus their attention on activities such as drug use that provide short-term relief.

Several mechanisms are protective for male youth who do not prefer immediate gratification; one mechanism may involve delay of responding. Low DD male youth, who are able to delay gratification, may be likely to gather information and consider alternatives before acting when they feel stressed. This orientation towards delayed gratification could effectively counteract a tendency for young men to respond impulsively and gravitate towards drug use in stressful situations. Another mode of operation could involve the ability to organize sequences of behavior and consider linkages across time [27]. During stressful periods this approach involves anticipating events, planning responses and considering the costs and benefits of various plans by recalling previous behavioral outcomes; this could help young men to avert the use of drugs as a coping mechanism. A preference for delayed gratification also could encourage affiliations with like-minded peers, further helping to forestall drug use during times of stress. Risk-enhancing and protective moderation effects of DD on young men may occur through a combination of cognitive, efficacy-oriented and social modes of operation. Clearly, research is needed

to test the variety of modes that contribute to the obtained moderation effects.

As expected, the interaction effect of SNS activation and DD on drug use emerged for young men but not young women. We propose two explanations for this finding. First, drug use rates were higher among young men than young women, at both ages 19 and 20. Higher rates of drug use render interactions easier to detect. A much larger sample than the present one could include female youth who engage in higher rates of drug use than did those in this study, permitting an adequately powered test. Secondly, gender differences in drug use rates may reflect a tendency for young men and young women to resort to different behaviors as coping tactics. Whereas young men tend to resort to DD and drug use, young women appear to seek appetitive stimuli other than drugs, such as energy-dense food [28]. Catecholamine levels may not act as a good predictive marker for drug use in young women. Stress-related physiology may be associated more strongly with impulsivity in young men. Future research should address the possibility of such gender differences.

Several limitations of the present study should be noted. The findings' generalizability to ethnically and socio-economically diverse samples drawn from either rural or urban communities, either within or outside the United States, must be established empirically. Studies with larger samples are also needed to examine processes that are responsible for the DD moderation effects. The processes that we suggested could be operating should be examined in future research. Finally, the interaction of catecholamines and DD in young men demonstrates the need for prevention programs that mitigate the potential for life stress to 'get under the skin'. This finding suggests that developing adaptive ways for individuals at high risk for socio-economic and psychosocial adversity to manage stress, and thus avert SNS activation and a preference for immediate rewards, may be a key strategy for preventing drug use and abuse.

Declaration of interests

None.

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