Neurocognitive Characteristics of Early Marijuana Use Initiation in Adolescents: A Signature Mapping Analysis

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ABSTRACT. Objective: Prior studies of the association between neurocognitive functions and marijuana use among adolescents are mostly cross-sectional and conducted in adolescents who have already initiated marijuana use. The current study used a longitudinal design on a pre-adolescent, substance-naïve sample. We sought to identify demographic factors associated with neurocognitive functions and the complement of neurocognitive function characteristics that predict marijuana initiation in adolescents. **Method:** Substance-naïve adolescents ($n = 465$) ages 10–12 years (51% male) were recruited from a community with high levels of adolescent marijuana use and prospectively followed to ages 12–15. Tasks measuring neurocognitive functions were administered and audio-assisted interviews were conducted. Two types of models were estimated for each outcome: forced-entry models and another using stepwise selection via bidirectional elimination with varying tolerance levels to account for selection misspecification. **Results:** About 10% ($n = 49$) initiated marijuana use over the study period. Child's age, aca-

demic achievement, and parental education were associated with baseline neurocognitive functions; namely, positive emotion attributions and lower impulsivity. Facial recognition—particularly misattribution of sad faces—was the strongest predictor of marijuana initiation, including in the stepwise model (partial OR = 1.3, 95% CI [1.03, 1.63], $p < .05$) that resulted in the best-fitting model. **Conclusions:** Prediction of marijuana initiation was improved in stepwise models compared with forced-entry models. Emotion perception appears to be an early developmental risk factor that is prospectively associated with marijuana initiation; as expected, other neurocognitive functions did not play an interactive role. Future studies of the interrelationships between emotion perception and the myriad other factors implicated in marijuana initiation, including neurocognitive functions not measured here, will provide a more-comprehensive understanding of risk for marijuana initiation. (*J. Stud. Alcohol Drugs*, 77, 431–440, 2016)

SURPRISINGLY LITTLE IS KNOWN about the precursors of marijuana use. Most studies have focused on adolescents who have already initiated drug use, and therefore the study of precursors has been confounded by the presence of consequences. Of particular interest is evidence that neurocognitive function may be negatively affected by marijuana use (Jager & Ramsey, 2008). Without a substance-naïve baseline, however, such conclusions are unfounded, particularly in view of evidence that some aspects of neurocognitive functions may increase propensity to use and are not simply consequential (Kirisci et al., 2007, 2009). To advance scientific understanding of neurocognitive vulnerability to marijuana use, prospective longitudinal studies with a drug-naïve baseline are needed.

The umbrella term *neurocognitive* is used here to reflect a range of higher order executive cognitive functions, emotional regulatory responses, and subservient cognitive functions. Level of executive cognitive function and its modulation of emotional arousal levels (e.g., perception

of emotional stimuli) represent key dimensions of regulatory processes related to risk for marijuana initiation and escalation (Dawes et al., 2000; Kirisci et al., 2009). Executive cognitive functions encompass the skills necessary for purposeful, goal-directed decision-making activity, behavioral inhibition, attention, and other prerequisites for social and coping behaviors. As such, impaired executive cognitive functions compromise abilities to interpret social cues, generate alternative socially adaptive behavioral responses, and execute a sequence of responses necessary to avoid or cope with various environmental and psychosocial challenges (Giancola, 1995; Karbach & Unger, 2014). A sizable prevalence of deficits in these abilities has been reported in countless studies of adolescent risk for substance misuse and associated behaviors (e.g., conduct disorder, impulsivity, disadvantageous decision making, aggression) (Becker et al., 2014; Day et al., 2013; Gruber et al., 2012; Thames et al., 2014).

Deficits in executive cognitive functions further influence emotional responses via a reduction in inhibitory controls and/or inaccurate appraisals of and responses to environmental or interpersonal inputs. Dysfunction in the neural network that modulates these functions (i.e., the cortic limbic circuit; Morawetz et al., 2015), and the cognitive and emotional regulatory problems that result, have been implicated in substance misuse (Fishbein et al., 2005; Geier, 2013; Uekermann et al., 2005). Interestingly, adolescence is

Received: June 3, 2015. Revision: August 29, 2015.

This research was funded by National Institute on Drug Abuse Grant 1R01DA022321.

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a developmental phase during which this neural circuitry is not yet fully connected; thus, although cognitive functioning is intact, its ability to engage in vertical control over emotional responses is not mature (Luna & Sweeney, 2004). The result is a heightened period of risk taking during adolescence. However, delays and deficits in executive cognitive functions are more extreme in some individuals for various reasons, often leading to maladaptive behaviors (Hare et al., 2008).

Studies using cognitive and emotional regulatory tasks and neurobiological measures that activate this circuitry implicate a combination of interrelated executive cognitive functions and emotional regulatory functions in marijuana initiation and misuse (Day et al., 2013; Geier, 2013; Gruber et al., 2012; Hare et al., 2008). Executive cognitive function tasks that discriminate between adolescents who initiate or escalate use of marijuana measure the ability to shift behavioral strategies in response to anticipated consequences, attention, decision making, planning, and impulse control (Crean et al., 2011; Kirisci et al., 2009; Sagar et al., 2015). Intelligence and verbal learning are also important substrates of these abilities. Further, those who tend to misattribute emotional cues, show attentional bias to emotionally salient stimuli, and are cognitively inflexible often exhibit maladaptive responses to social cues. In addition, there is increased propensity to negative affect, poor coping skills in response to social challenges, and difficulty redirecting maladaptive behaviors. Combined, these tendencies are believed to increase risk for initiation of marijuana use. Thus, ways in which executive cognitive functions and emotion perception interact to influence ability to orchestrate responses in the form of effective and adaptive behaviors may help us to understand marijuana use initiation; their reciprocal influence must be studied in tandem (Silveri et al., 2004; Simons & Carey, 2002).

Purposes of the present study

Like many biological systems, the pathways linking neurocognitive function dimensions are not unidirectional and linear. Rather, there is a complex set of feedback loops that drive responses to environmental stimuli and ultimately interact in complex ways to produce behaviors. Studies that model these constructs as single entities to assess the extent to which they independently and relatively explain variance in any given outcome may be misleading. Using a data-mining technique well suited to elucidate clusters of potentially influential factors, the current study used a longitudinal panel of substance-naïve adolescents to test the hypothesis that neurocognitive functions would significantly predict marijuana initiation. Our substance-naïve baseline condition allowed us to prospectively track participants and predict initiation using a battery of neurocognitive function tasks to assess their relative and combined predictive value.

With an array of variables that tap different dimensions of neurocognitive functions, these assessments use data-reduction techniques of stepwise regression, thus allowing us to identify the complex interactions and interdependencies that are aligned with the theoretical understanding of the brain-behavioral functional linkages.

Method

Population

Drug- and alcohol-naïve youth were initially identified as high risk based on residence in a community known for very high levels of early marijuana use (Covington, KY), compared with national data (Furlong et al., 2003) and local data (Kentucky Youth Survey; Novak & Clayton, 2001), providing for an adequate sample of eventual, early-onset users. Schools were identified first by local contact with administrators. Recruitment began for Wave 1 with Covington school district staff allowing access to information on enrolled youth who were 10, 11, and 12 years of age. A variety of subject-recruitment strategies were used, as follows: (a) distributing flyers and displaying posters in schools, (b) mailing age-eligible households a Superintendent's endorsement letter and study brochure, and (c) contacting primary caregivers directly. Written informed consent was obtained from the caregiver and written assent was obtained from the child. Eligibility criteria included (a) child age between 10 and 12 years at the time of consent; (b) residence in Covington, KY, at the time of the baseline survey; (c) ability and willingness to provide consent; and (d) never consumed more than prespecified small amounts of alcohol (e.g., less than one drink) and no use of illicit drugs by the time of baseline interview.

For the first wave of data collection, we assessed 529 10- to 12-year-old, drug- and alcohol-naïve pre-adolescents in the Covington, KY, school system. Participants were informed during the recruitment and consent process that they might be tested for marijuana. A short survey was used to screen for eligibility of interested participants, and, in a more-extensive questionnaire, endorsement of no prior marijuana use was used to exclude participants. At baseline, three participants who reported marijuana use were inadvertently admitted into the study; however, they were excluded from all analyses. Fifteen cases with IQs less than 70 (based on the Kaufman Brief Intelligence Test–Second Edition [KBIT-2; Kaufman & Kaufman, 2004]) were excluded from analyses at baseline. Overall, 79% of eligible participants agreed to participate in the study and were provided a screening instrument. We also interviewed primary caregivers. In Wave 2 we assessed 489 (93%) of the Wave 1 caregiver/child cohort, at which time the children were 12–15 years of age. There were no new cases of IQ less than 70 at the second wave of data collection.

Instrumentation

In both study waves, field staff conducted separate sessions with caregiver and child within the household in a private location. Interviews were computer assisted, and sensitive content questions were asked using audio computer-assisted (ACASI) technology. The caregiver interview provided both prospective and retrospective information on change in various relevant conditions over the course of Waves 1 and 2. Domains covered in both interviews related to possible neurodevelopmental and environmental and experiential precursors and consequences of their child's marijuana and other drug use and other corollary risk behaviors. Various survey measures and a neurocognitive battery of executive cognitive and emotional regulatory tasks were administered to the child. Parents also responded to several surveys and were compensated with cash, while youth were given gift cards. Once the youth session was completed, participants were compensated, reminded of their next appointment, and provided with contact information if there were any questions or concerns.

Measures of neurocognitive functioning

Level of neurodevelopment was reflected in several computerized tasks measuring dimensions of executive cognitive functions and emotion perception. General intelligence was estimated using the KBIT-2, a measure primarily of nonverbal reasoning and language. This test is manually administered and produces a score for full scale IQ.

The Rey Auditory Verbal Learning Test (Schmidt, 2004) is a brief, easily administered paper-and-pencil measure that assesses immediate memory span, new learning, susceptibility to interference, and recognition memory. Outcome variables include confabulations (words cited that are not on the list), intrusions (words that the examiner may have used in an earlier test in the battery), and perseverations (repeated words), the recognition score for the number of words correctly circled on the sheet, and the number of incorrect words circled on the recognition trial.

The Vigilance Continuous Performance Test (Vigilance CPT; Ehrenreich et al., 1999; Jacobsen et al., 2004; Schneider & Detweiler, 1987) consists of a 2×2 matrix (4 cm $\times$ 4 cm) comprising two letters and two solid blocks presented on a computer screen. Subjects are shown a sequence of letters located in different positions in the matrix at a rate of 900 msec. The dependent measure is the total number of times the subject makes a response to a non-target letter. Such commission errors reflect an inability to inhibit incorrect responding under circumstances involving sustained attention.

The Motor Restraint Task (MRT) measures inhibition of impulsive motor output while executing a controlled

slow motoric response (Parsons et al., 1972). Subjects are asked to trace a 180-degree arc—as slowly as possible—on a touch screen laptop using a lightpen. Success on this task requires the capacity to inhibit impulsive motor output while executing a controlled slow motoric response. The key data point is time during the traversing minus the total time of stoppages.

The Iowa Gambling Task (Bechara et al., 1994, 1997; Whitlow et al., 2004) is a computerized measure of ability to develop a decision-making strategy based on previously learned information and sensitivity to consequences. The “Wheel of Fortune” (WoF) version (Ernst et al., 2003; Shad et al., 2011) was adapted to be developmentally appropriate for young adolescents. Players must develop a strategy to maximize gain, balancing between rewards and penalties; the disadvantageous strategy is the selection of large rewards with greater odds of losing those rewards. Outcome measures included percentage of risky selections, percentage of safe selections, and the risky/safe ratio.

Trail Making Tests (TMT; Lezak et al., 2004) measure speed for attention, sequencing, mental flexibility, and visual search and motor function. Trails A and B are the primary measures used, reflecting the connection, by making stylus lines, between 15 encircled numbers randomly arranged on a page in proper order (A) and of 15 encircled numbers and letters in alternating order (B). This task is performed on a touch screen laptop.

The Porteus Maze Test (Porteus, 1965) requires subjects to navigate their way through eight mazes using a touch screen laptop. They are instructed to not lift their stylus from the screen until each maze is completed. The Impulsive Errors score comprised the dependent measure. This type of error reflects poor planning abilities, a lack of foresight, poor judgment, and an inability to learn from experience.

The Facial Recognition Task (FACES; Eckman & Friesen, 1975) uses facial pictures to measure emotional perception (Silveri et al., 2004; Simons and Carey, 2002; Tottenham et al., 2009). Six emotional expressions were presented for respondents to identify: happiness, sadness, anger, surprise, disgust, and fear. Number of expressions correctly identified and a total score were generated.

An Emotional Stroop Task (Pérez-Edgar & Fox, 2003) assessed the interference generated by emotional stimuli (positive and negative) in processing cognitive stimuli (words). Participants were presented with 45 words, 15 in each word category: positive, negative, and control. The words were chosen as representatives of broad affective states. Children were asked to state the color in which the word was written, while disregarding the content of the word. Number of correctly stated words in each category and reaction times are primary outcome measures with the control condition accuracy and reaction time rates subtracted from both the positive and negative rates.

Measures of drug and alcohol use

The eligibility criterion was that substance use (e.g., alcohol, marijuana, cocaine, heroin, amphetamines, opiates, hallucinogens, and others) had not exceeded a prespecified amount (e.g., less than one drink and no use of illicit drugs) by the time of baseline interview. Determination was made by a detailed and well-established interview with multiple “double check” items. We used ACASI technology, which further encourages accurate reporting (Hewett et al., 2004; Richter & Johnson, 2001). Testing took place in a private location, and respondents were repeatedly reminded that all responses were confidential and would be reported in an anonymous fashion.

The nature and extent of drug use at Wave 2 was measured via a lengthy, detailed survey adapted from three large national surveys: the National Survey on Drug Use and Health (formerly known as the National Household Survey on Drug Abuse), the Monitoring the Future (MTF) Survey, and the Youth Risk Behavior Survey (YRBS). The MTF and YRBS are school-based surveys. For purposes of the present study, only the initiation of marijuana variable was used. We considered, but decided against, including covariates for initiation of other substances, because the goal of this study was to first explore the nature of neurocognitive functions on marijuana initiation. This preliminary goal is a crucial first step in identifying the structural model to be tested in future studies that seek to more stringently identify the relevant confounders using more-sophisticated techniques that can better support causal inferences.

Statistical analysis strategy

The study maintained a high retention rate between waves (93%), and preliminary analyses indicated no statistically significant predictors of attrition. The modal reason for attrition was moving residence out of state (90%), followed by failure to locate (8%) and refusal (2%). Given the small number of missing cases at the item level, the listwise deletion procedure was used to eliminate any biases that might be introduced by missing observations. We report the unadjusted *p* values—rather than correcting for number of statistical tests—because the analyses presented were based on a priori hypotheses tests planned before study initiation rather than exploratory post hoc analyses. SAS (Release 10.0.3; SAS Institute Inc., Cary, NC) was used.

The primary analytic strategy was based on the general linear model to first identify the characteristics associated with neurocognitive functions. To illustrate, many executive cognitive function abilities improve rapidly over the course of early adolescence, making it important to statistically control for normative, age-related maturation of executive cognitive functions. Once identified, those same characteristics would serve as candidate control variables in the

second portion of the analysis, which was to use the standard logistic regression model to identify the neurocognitive predictors that account for unique cases of marijuana use initiation. The lagged modeling approach was used, in which the follow-up wave value of initiation was regressed on baseline characteristics. Marijuana-naïve youth were recruited into the study; three cases reported initiation of marijuana between recruitment and the baseline measurement and were excluded from analyses. Fixed-effect models were preferred over random-effect and proportional hazard models because the time interval between baseline and follow-up was the same for each youth, and the sample age was also fixed at specific ages (i.e., 10–12), approximating the developmental transition from middle school to high school ages over the 30-month observational window.

Model fitting proceeded in a sequence to identify the combination of neurocognitive function dimensions predictive of marijuana initiation using model specifications that allowed for an a priori and hypothesized unique “signature” structure of functions. This method may more faithfully represent the complex and interdependent structure of neurocognitive function dimensions that, in real-world contexts, cannot—and perhaps should not—be separated in attempts to understand complex human behavior. Therefore, the use of data-mining procedures, in comparison with traditional forced-entry approaches, could lend insight into a more-comprehensive delineation of functional predictors of any given clinical phenomenon during this period of psychosocial and neurological development.

Data mining was conducted using standard stepwise regression methods, including forward and backward selection procedures, to arrive at the model that best represents the observed data. The selection was limited to the candidate neurocognitive function variables thought to confer risk/resiliency to marijuana use initiation. In stepwise selection, information criteria are a guiding principal to determine optimal selection. We used an informational criterion based on the adjusted Akaike information criterion (AIC) and Bayesian information criterion (BIC) for the number of unique parameters. The problem for model selection is that the number of models is exponentially linked to the number of variables. If we have 10 explanatory variables, then there are 1,024 (2 to the 10th power) possible models. With 20 variables, there are more than 1 million, and 34 variables leaves us with close to 16 billion candidate models. Thus, a reasonable and economical method is to introduce entry and retention criteria into the model for variables at fairly high thresholds (>.99). This allows for a more-parsimonious number of comparisons based on a smaller number of directly comparable models due to higher selection and retention criteria.

Overall, there were four regression models that were estimated. The first two were forced-entry models, such that a bivariable model was used to estimate the total effect between each neurocognitive function factor and initiation.

A multivariable model was used to estimate the direct effect of each neurocognitive function, controlling for demographic factors (e.g., age, gender). In the next two sets of models, we estimated stepwise regression models, one in which the entire list of neurocognitive function variables was used as selection variables. A final model included the list of neurocognitive function variables as well as the demographic factors.

Results

Baseline characteristics of marijuana initiates

Table 1 shows the parental and child demographic characteristics for the entire sample, for those youth who remained abstinent between baseline and follow-up, and for those who initiated marijuana use. Because this was a general population survey, the data are comparable to the community of youth in northern Kentucky. The initial sample exhibited diversity in child's sex (51% male, 49% female), race (53% White, 30% Black, and 17% other), and academic competence (37% mostly "A's" to 3% mostly "F's"). The caregivers were mostly female (91%) and the child's biological parent (90%). There was large diversity in caregiver age ($M = 36$ years, range: 23–73) and educational attainment (27% less than high school, 38% high school graduate/General Educational Development (GED) credential, 29% some college, and 6% college graduate or higher).

Of the characteristics identified, there were significant differences in initiation of marijuana: Initiates were more likely to be older ($p < .003$) and of a higher school grade ($p < .005$) than non-initiates. Marijuana initiates were also more likely to have used cigarettes (20% vs. 7%) and alcohol (16% vs. 5%) than nonusers of these substances at baseline. However, demographic factors such as school performance, parental academic achievement, and parental and child sex/race were not different between initiates and non-initiates. Among initiates, a large majority (75%) had used on only 1–2 days.

Baseline correlates of neurocognitive dimensions

Bivariate associations between demographic characteristics and neurocognitive function constructs appear in Table 2.

Age. The regression models showed that age was significantly associated with four of the eight neurocognitive function tasks: FACES, TMT, MRT, and the impulsivity CPT. Overall, it was largely associated with positive performance on each of these tasks. To illustrate, for the score on the FACES test examining the NEUTRAL outcome, approximately 7 answers (of 10) was the average response, and each year increase in age corresponded with 0.20 increase in the score. Regarding the TMT, increases in age were also associated with a higher standardized time for both cognitive processing speed (Trial A, $M = 43.4$) and executive cogni-

TABLE 1. Sample demographics

Variable	Total ($N = 465$) %	Abstinent ($n = 416$) %	Initiates ($n = 49$) %
Children			
Age*			
10	40.2	42.8	18.3
11	28.2	27.6	32.7
12	30.5	28.4	49.0
13	1.1	1.2	0
Sex			
Male	51.4	51.7	49.0
Female	48.6	48.3	51.0
Race			
White	52.5	51.2	63.3
Black	30.3	31.0	24.5
Other	17.2	17.8	12.2
Child's grade*			
3rd	2.1	1.9	2.1
4th	23.7	25.5	12.5
5th	30.9	32.8	18.8
6th	26.1	24.6	39.6
7th	15.8	14.5	22.9
8th	1.4	0.8	4.2
School performance			
Mostly A's	37.4	39.6	26.5
Mostly B's	40.5	40.1	42.9
Mostly C's	15.1	13.6	24.5
Mostly D's	3.7	3.6	4.1
Mostly F's	3.3	3.2	2.0
Substance use, ever			
Cigarettes*	7.8	6.5	20.4
Alcohol*	5.8	4.6	16.3
Illicit drugs	2.4	2.4	2.4
Caregiver			
Gender			
Male	8.8	9.4	4.1
Female	91.2	90.6	95.9
Relationship to child*			
Biological parent	89.9	91.1	79.6
Biological relative	6.3	5.8	10.2
Other	3.9	3.1	10.2
Age, M (SD)	36.4 (8.1)	36.3 (7.9)	37.4 (9.9)
Education			
Less than high school	26.8	27.1	24.5
High school/GED	38.4	37.3	48.9
Some college	28.8	29.5	22.5
College graduate	5.8	6.1	4.1

Notes: GED = General Educational Development credential.

* $p < .05$.

tive performance (Trail B, $M = 37.58$). Higher age was also associated with higher levels of motor restraint and lower levels of impulsivity as measured by the Conner's CPT. Age was also negatively associated with attention deficits, with the exception of the Commission measure.

Sex. There were sex differences for only a small number of tests. Compared with girls, boys exhibited lower levels of facial recognition, specifically on SURPRISE, ANGER, FEAR, SADNESS, and DISGUST. With regard to dimensions of impulsivity and decision making, boys exhibited poorer performance on the WoF and the impulsivity CPT. On the WoF, boys were less likely than girls to select safe bets,

TABLE 2a. Potential confounding factors of effects of neurocognition

			FACES								KBIT-2		Stroop		TMT	
			Total	Neutral	Surprise	Anger	Fear	Happy	Sad	Disgust	Verbal	Non-verbal	Negative	Positive	Trail A	Trail B
Age, child	Intercept	β_0	32.33	6.95	6.93	4.86	4.56	7.86	2.59	2.92	94.66	117.04	25.83	-8.14	40.17	23.55
		β_1	1.72	0.20	0.13	0.26	-0.01	0.15	0.39	0.29	0.32	-1.62	-6.25	-2.16	3.31	4.03
Sex, child	Female ^a	β_0	52.70	9.12	8.52	7.87	4.62	9.55	7.20	6.47	97.47	98.76	-39.14	-34.90	75.77	65.47
		β_1	-3.14	-0.02	-0.31	-0.42	-0.46	-0.15	-0.62	-0.68	1.37	1.11	-6.52	6.18	1.28	4.34
Caregiver	<HS grad. ^a	β_0	49.13	8.99	7.80	7.91	4.10	9.14	7.02	5.43	90.81	96.28	-26.11	-8.01	71.37	63.57
Education	≥HS grad.	β_1	0.92	0.06	0.26	-0.11	0.14	0.16	-0.06	0.33	3.42	1.42	-7.60	-11.06	2.34	1.91

Notes: **Bold** indicates $p < .05$ (two tailed). Only participants with IQ > 70 and having complete data at both waves ($n = 465$) were included. FACES = Facial Recognition Task; KBIT-2 = Kaufman Brief Intelligence Test, Second Edition; TMT = Trail Making Test; β_0 = intercept; β = regression coefficient; HS grad. = high school graduate. ^aReference category.

TABLE 2b. Associations between baseline demographics and child baseline neurocognitive factors

			MRT		WoF		RAVLT		Impulsivity CPT				Vigilance CPT			
Variable			Total time	Stop time	Safe	Risky	Recog.	Confab.	Omis.	Comm.	Inc.	RT	Omis.	Comm.	Inc.	RT
Age, child	Intercept	β_0	8,647	-0.22	11.01	7.99	10.04	1.14	249.98	13.90	263.35	519.39	29.74	40.73	70.33	519.39
		β_1	1,435	0.09	0.24	-0.24	0.26	-0.05	-15.05	0.38	-14.62	-11.67	-1.69	-2.23	-3.92	-11.67
Sex, child	Female ^a	β_0	25,244	0.87	14.06	4.94	13.13	0.58	95.01	16.07	111.08	405.19	11.29	15.17	26.41	405.19
		β_1	-1,734	-0.25	-0.91	0.91	-0.49	0.08	-18.79	3.86	-15.01	-26.51	-0.02	2.21	2.10	-26.51
Caregiver	<HS grad. ^a	β_0	22,044	0.61	13.56	5.44	12.69	0.59	87.54	18.42	105.91	392.35	11.51	18.14	29.77	392.35
Education	≥HS grad.	β_1	1,074	0.06	0.02	-0.02	0.09	0.01	-0.97	-0.18	-1.15	-0.30	-0.11	-0.86	-1.07	-0.30

Notes: **Bold** indicates $p < .05$ (two tailed). Only participants with IQ > 70 and having complete data at both waves ($n = 465$) were included. MRT = Motor Restraint Task; WoF = Wheel of Fortune; RAVLT = Rey Auditory Verbal Learning Test; CPT = Continuous Performance Test; recog. = recognition; confab. = confabulation; omis. = omission; comm. = commission; inc. = incorrect; RT = reaction time; β_0 = intercept; β = regression coefficient; HS grad. = high school graduate. ^aReference category.

more often chose riskier bets, and exhibited less impulse control across the impulsivity CPT.

Race. No racial differences in the neurocognitive functions were observed except for the KBIT-2, on which Blacks scored slightly lower than other groups.

Grades. There were no consistent or meaningful associations for grade point averages.

Substance use. Initiation of tobacco, alcohol, and illicit drugs other than marijuana were unrelated to neurocognitive functions. This was in part because of the small number of initiators of substances other than marijuana.

Caregiver characteristics. Having a parent who graduated high school or had more education was related to higher scores on the FACES by about 1 answer (TOTAL) and higher scores on the child's KBIT-2 measure of intelligence for verbal (by 3.4) and nonverbal (by 1.4) IQ.

Signature analyses: Baseline neurocognitive characteristics on marijuana initiation

Table 3 shows the regression of the neurocognitive functions baseline characteristics on subsequent marijuana initiation. The first model (Model 1) shows the bivariate associations between each separate NCF and marijuana initiation. The statistically significant associations were between FACES (DISGUST odds ratio [OR] = 1.21, 95% CI [1.05, 1.41], $p < .01$), Stroop (Positive-Control: OR = 1.01, 95% CI [1.001, 1.06], $p < .05$), and TMT (Trails A—Cognitive

Processing Speed: OR = 1.01, 95% CI [1.01, 1.02], $p < .05$). An additional association became statistically significant after we controlled for demographics with FACES (SAD: OR = 1.22, 95% CI [1.01, 1.42], $p < .05$).

The third and fourth models in Table 3 represent the stepwise selection procedure in an attempt to develop the neurocognitive functions signature that accounted for unique variance in marijuana initiation. The lone statistically significant neurocognitive functions coefficients were for FACES (SAD, OR = 1.31, 95% CI [1.03, 1.63], $p < .05$) and Stroop Positive-Control (OR = 1.01, 95% CI [1.00, 1.01], $p < .05$). The final model added the covariates from Table 2a/2b as candidate factors for inclusion/exclusion. The lone statistically significant predictor was FACES/SAD (OR = 1.36, 95% CI [1.06, 1.74], $p < .05$). Model 3 exhibited the overall best fit to the data, based on the lowest AIC/BIC and omnibus fit statistics.

Discussion

The present study examined the association between neurocognitive function abilities and marijuana initiation within an early pre-adolescent developmental window, ages 10–12 years. There were few consistent demographic predictors of neurocognitive functions, with the exception of the child's age, academic performance, and parental academic achievement. There were also only a few differences related to sex and race, as well as prior risk associated with previ-

TABLE 3. Bivariate characteristics of baseline neurocognitive functioning on initiation of marijuana use: Forced and stepwise initiates

Variable	Model 1: Bivariable		Model 2: Multivariable		Model 3: Stepwise		Model 4: Stepwise with covariates	
	OR	[95% CI]	OR	[95% CI]	OR	[95% CI]	OR	[95% CI]
FACES								
Total score	1.01	[0.97, 1.05]	1.03	[0.99, 1.08]				
Neutral	1.00	[0.84, 1.19]	1.05	[0.86, 1.29]				
Surprise	1.10	[0.87, 1.38]	1.20	[0.93, 1.54]				
Anger	0.91	[0.77, 1.06]	0.93	[0.78, 1.10]	0.81	[0.63, 1.04]	0.82	[0.62, 1.08]
Fear	0.92	[0.80, 1.06]	0.95	[0.82, 1.10]	0.90	[0.76, 1.07]	0.90	[0.76, 1.07]
Happy	0.91	[0.75, 1.12]	0.97	[0.77, 1.22]				
Sad	1.15	[0.97, 1.35]	1.22	[1.01, 1.42]	1.31	[1.03, 1.63]	1.36	[1.06, 1.74]
Disgust	1.21	[1.05, 1.41]	1.27	[1.07, 1.49]	1.19	[0.99, 1.43]	1.17	[0.98, 1.45]
KBIT-2								
Verbal	1.00	[0.97, 1.02]	1.00	[0.98, 1.03]				
Nonverbal	0.99	[0.97, 1.02]	0.99	[0.97, 1.02]	0.97	[0.94, 1.00]	0.97	[0.94, 1.00]
Stroop								
Negative-Control	1.01	[0.99, 1.00]	1.01	[0.99, 1.00]				
Positive-Control	1.00	[1.00, 1.06]	1.00	[1.00, 1.01]	1.00	[1.00, 1.01]	1.00	[1.00, 1.01]
TMT								
Trial A	1.01	[1.00, 1.02]	1.01	[1.01, 1.03]	1.01	[0.99, 1.02]	1.13	[0.92, 1.34]
Trial B	1.00	[0.99, 1.01]	1.00	[0.99, 1.01]				
MRT								
Total time	1.00	1.00	1.00	1.00				
Total stop error	1.08	[0.91, 1.27]	1.06	[0.88, 1.27]	1.14	[0.94, 1.38]	1.01	[0.99, 1.02]
WoF								
Total no. of safe bets	0.95	[0.89, 1.02]	0.96	[0.89, 1.03]				
Total no. of risky bets	1.04	[0.97, 1.12]	1.03	[0.96, 1.12]	1.05	[0.97, 1.13]	1.05	[0.96, 1.14]
RAVLT								
Recognitions	1.06	[0.93, 1.20]	1.10	[0.95, 1.26]				
Confabulation words	0.98	[0.83, 1.16]	0.97	[0.80, 1.17]				
Impulsivity								
Omissions	0.99	[0.99, 1.00]	0.99	[0.99, 1.00]				
CPT								
Commissions	1.00	[0.95, 1.05]	1.00	[0.94, 1.06]				
Incorrect	0.99	[0.99, 1.00]	0.99	[0.99, 1.00]				
Reaction time	1.00	[0.99, 1.00]	1.00	[0.99, 1.01]				
Vigilance								
Omissions	0.99	[0.96, 1.02]	0.99	[0.96, 1.02]				
CPT								
Commissions	0.99	[0.97, 1.00]	0.99	[0.97, 1.00]	0.97	[0.95, 1.00]	0.98	[0.95, 1.00]
Incorrect	0.94	[0.98, 1.00]	0.99	[0.98, 1.00]				
Reaction time	1.00	[0.99, 1.00]	0.99	[0.99, 1.00]				

Notes: **Bold** indicates $p < .05$. Covariate controls are all variables listed in Table 2. OR = odds ratio; CI = confidence interval; FACES = Facial Recognition Task; KBIT-2 = Kaufman Brief Intelligence Test, Second Edition; TMT = Trail Making Test; MRT = Motor Restraint Task; WoF = Wheel of Fortune; no. = number; RAVLT = Rey Auditory Verbal Learning Test; CPT = Continuous Performance Test.

ous initiation of alcohol, tobacco, and illicit drugs. Most of the neurocognitive function dimensions that were associated with the child and the primary caregiver's predictors of youth marijuana initiation were largely concentrated in the dimensions of impulsivity and facial recognition, and to a lesser extent intelligence and attention.

The primary hypothesis of this study was that neurocognitive functions would significantly predict marijuana initiation and that the data-mining technique conferred by the stepwise regression would provide the best fitting model to the data. The stepwise model approach did provide a unique aspect in terms of highlighting different dimensions that were statistically nonsignificant in the forced-entry models. The bivariable approach provided the method that best allowed for maximum detection of the greatest num-

ber of statistically significant findings, although at a lower effect size. As noted in the introduction, the neurocognitive functions system is complex, and dimensions are highly interdependent. It appears from this study that a diverse range of forced-entry and data-mining techniques are needed to better understand how to develop and test statistical models that more faithfully and accurately represent the true nature of the data.

Across all models, the FACES SAD measure was the most powerful and consistent predictor of marijuana initiation. Participants who were more accurate in facial recognition of a SAD mood were 30% more likely to initiate marijuana use. The result persists after multiple correction biases; the additional steps taken in these analyses were designed to reduce the probability of chance findings.

Although there is some theoretical basis for this finding, discrepancies in the literature exist. Chepenik et al. (2007), for example, reported that sad mood interfered with recognition of emotional expressions; the opposite of our finding. Frigerio et al. (2002) also reported that alcoholics tend to misattribute sadness for anger and disgust, as do both children and adults with various psychiatric disorders. Thus, our initial expectations were that marijuana initiators may have difficulty attributing sad (and other) emotional expressions as a possible proxy for depressed mood, a consistently strong predictor of substance use in numerous studies (Hussong et al., 2011; Rao & Chen, 2008).

However, there are studies to suggest that individuals who are more sensitive to their own emotional states and those of others may be more prone to depression (Lopez-Duran et al., 2013), which may, in turn, increase risk for substance misuse. Along those lines, Ernst et al. (2010) reported that adolescents who initiated substance use showed greater recognition of angry emotion, suggesting a bias toward negative emotion. Facial emotion recognition in general may be a social skill that plays a role in risky behaviors; however, it remains unclear as to the nature of its relationship to substance use and these seemingly discrepant findings. The mixed results may be attributable to important individual differences or interactions with characteristics that only affect subgroups of youth (especially in light of the complexity of associations between executive cognitive functions and substance use that was described earlier). Additional studies are needed to address these questions. Mechanisms that underlie the influence of eventual use on the neural substrates of these skills may be targets for new interventions.

The study has some important limitations that should be noted. First, with only two data points at an early stage of development, we were unable to assess how the relations between neurocognitive function dimensions and marijuana initiation differ by age. For example, there are important neurological and psychosocial changes across the developmental period of early adolescence through young adulthood.

A second limitation to consider is that we only used one type of data-mining technique—stepwise regression. There are numerous other methods (e.g., neural networks analysis) that may be used. However, our goal was to use the technique most familiar to social scientists to call attention to the potential for using complementary forced-entry and unsupervised data-mining techniques when there is a strong theoretical and/or evidence base underlying the assumptions. The rationale is that the neurocognitive functions system is highly interconnected and interdependent, with complex pathways involving multiple mediators and moderators that operate in concert to influence behavior. Stepwise methodology carries an advantage to the study of neurocognitive functions and drug use initiation in that it can provide an initial step in identifying subtle interactions that are driven

by suppression. Holding the appropriate types of variables constant will aid in the detection of “hidden” relationships. Therefore, the ultimate value of this study is to illustrate how key neurocognitive function variables optimally combine, suggesting either plausible pathways in laboratory models or more-refined analyses with longitudinal data beyond the early risk period of young adolescence (ages 10–12).

A third limitation is that we were only able to examine whether the respondent initiated; we did not have sufficient power to examine differences among initiates in terms of levels of use during their year of initiation. The number of initiates in this early developmental window was small; thus, differences in the patterns of onset could not be analyzed separately. In analyses not shown, approximately half of the sample that initiated marijuana use reported using on only one occasion, whereas the remaining half used on multiple occasions. As the number of initiates accrues, we will be better able to examine the neurocognitive function characteristics predictive of initiation, particularly in those who escalate use, to generate more clinically meaningful findings than a focus on simple experimentation with marijuana.

In addition to the limitations noted above, we recognize that the sample may be viewed as having limited generalizability because it is drawn from a single community. However, comparisons with other large national data sources for the 12- and 13-year-old samples (e.g., Substance Abuse and Mental Health Services Administration, 2013) suggest strong comparability with respect to prevalence of marijuana initiation. Yet, it is also important to underscore the unique characteristics of the community studied in this work and the crucial nature of replication to further establish scientific reliability in the inferences drawn from this project.

In summary, further research to better understand the precursors and consequences of marijuana use in adolescence is crucial, particularly in light of the tremendous scrutiny in recent months with the legalization and medicalization of marijuana in numerous states. Policymakers require pertinent and complete information to guide decisions as to whether to fully legalize or more restrictively allow medical use of the substance, and research such as this can help us to understand the long-term precursors of initiation of marijuana use, as well as the potential adverse neurological effects that may occur after exposure. Confirmatory research, however, is necessary for policymaking and to inform design of preventive and treatment interventions. Support for these hypotheses suggest that early, targeted interventions may significantly, and perhaps enduringly, alter the developmental trajectory at crucial time points toward more-adaptive outcomes (i.e., no use).

Acknowledgments

The authors thank the RTI International field staff team for ensuring that this complex study was successfully executed.

References

- Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, 50, 7–15. doi:10.1016/0010-0277(94)90018-3
- Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*, 275, 1293–1295. doi:10.1126/science.275.5304.1293
- Becker, M. P., Collins, P. F., & Luciana, M. (2014). Neurocognition in college-aged daily marijuana users. *Journal of Clinical and Experimental Neuropsychology*, 36, 379–398. doi:10.1080/13803395.2014.893996
- Chepenik, L. G., Cornew, L. A., & Farah, M. J. (2007). The influence of sad mood on cognition. *Emotion*, 7, 802–811. doi:10.1037/1528-3542.7.4.802
- Crean, R. D., Crane, N. A., & Mason, B. J. (2011). An evidence based review of acute and long-term effects of cannabis use on executive cognitive functions. *Journal of Addiction Medicine*, 5, 1–8. doi:10.1097/ADM.0b013e31820c23fa
- Dawes, M. A., Antelman, S. M., Vanyukov, M. M., Giancola, P., Tarter, R. E., Susman, E. J., . . . Clark, D. B. (2000). Developmental sources of variation in liability to adolescent substance use disorders. *Drug and Alcohol Dependence*, 61, 3–14. doi:10.1016/S0376-8716(00)00120-4
- Day, A. M., Metrik, J., Spillane, N. S., & Kahler, C. W. (2013). Working memory and impulsivity predict marijuana-related problems among frequent users. *Drug and Alcohol Dependence*, 131, 171–174. doi:10.1016/j.drugalcdep.2012.12.016
- Eckman, P., & Friesen, W. V. (1975). *Unmasking the face*. Englewood Cliffs, NJ: Prentice-Hall.
- Ehrenreich, H., Rinn, T., Kunert, H. J., Moeller, M. R., Poser, W., Schilling, L., . . . Hoehe, M. R. (1999). Specific attentional dysfunction in adults following early start of cannabis use. *Psychopharmacology*, 142, 295–301. doi:10.1007/s002130050892
- Ernst, M., Grant, S. J., London, E. D., Contoreggi, C. S., Kimes, A. S., & Spurgeon, L. (2003). Decision making in adolescents with behavior disorders and adults with substance abuse. *American Journal of Psychiatry*, 160, 33–40. doi:10.1176/appi.ajp.160.1.33
- Ernst, M., Luckenbaugh, D. A., Moolchan, E. T., Temple, V. A., Jenness, J., Korelitz, K. E., . . . Kimes, A. S. (2010). Decision-making and facial emotion recognition as predictors of substance-use initiation among adolescents. *Addictive Behaviors*, 35, 286–289. doi:10.1016/j.addbeh.2009.10.014
- Fishbein, D. H., Eldreth, D. L., Hyde, C., Matochik, J. A., London, E. D., Contoreggi, C., . . . Grant, S. (2005). Risky decision making and the anterior cingulate cortex in abstinent drug abusers and nonusers. *Cognitive Brain Research*, 23, 119–136. doi:10.1016/j.cogbrainres.2004.12.010
- Frigerio, E., Burt, D. M., Montagne, B., Murray, L. K., & Perrett, D. I. (2002). Facial affect perception in alcoholics. *Psychiatry Research*, 113, 161–171. doi:10.1016/S0165-1781(02)00244-5
- Furlong, M., Paige, L. Z., & Osher, D. (2003). The Safe Schools/Healthy Students (SS/HS) Initiative: Lessons learned from implementing comprehensive youth development programs. *Psychology in the Schools*, 40, 447–456. doi:10.1002/pits.10102
- Geier, C. F. (2013). Adolescent cognitive control and reward processing: Implications for risk taking and substance use. *Hormones and Behavior*, 64, 333–342. doi:10.1016/j.yhbeh.2013.02.008
- Giancola, P. R. (1995). Evidence for dorsolateral and orbital prefrontal cortical involvement in the expression of aggressive behavior. *Aggressive Behavior*, 21, 431–450.
- Gruber, S. A., Sagar, K. A., Dahlgren, M. K., Racine, M., & Lukas, S. E. (2012). Age of onset of marijuana use and executive function. *Psychology of Addictive Behaviors*, 26, 496–506. doi:10.1037/a0026269
- Hare, T. A., Tottenham, N., Galvan, A., Voss, H. U., Glover, G. H., & Casey, B. J. (2008). Biological substrates of emotional reactivity and regulation in adolescence during an emotional go-nogo task. *Biological Psychiatry*, 63, 927–934. doi:10.1016/j.biopsych.2008.03.015
- Hewett, P. C., Mensch, B. S., & Erulkar, A. S. (2004). Consistency in the reporting of sexual behaviour by adolescent girls in Kenya: A comparison of interviewing methods. *Sexually Transmitted Infections*, 80, Supplement 2, ii43–ii48. doi:10.1136/sti.2004.013250
- Hussong, A. M., Jones, D. J., Stein, G. L., Baucom, D. H., & Boeding, S. (2011). An internalizing pathway to alcohol use and disorder. *Psychology of Addictive Behaviors*, 25, 390–404. doi:10.1037/a0024519
- Jacobsen, L. K., D'Souza, D. C., Mencl, W. E., Pugh, K. R., Skudlarski, P., & Krystal, J. H. (2004). Nicotine effects on brain function and functional connectivity in schizophrenia. *Biological Psychiatry*, 55, 850–858. doi:10.1016/j.biopsych.2003.12.023
- Jager, G., & Ramsey, N. F. (2008). Long-term consequences of adolescent cannabis exposure on the development of cognition, brain structure and function: An overview of animal and human research. *Current Drug Abuse Reviews*, 1, 114–123. doi:10.2174/1874473710801020114
- Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. *Frontiers in Psychology*, 5, 390. doi:10.3389/fpsyg.2014.00390
- Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test, Second Edition*. San Antonio, TX: Pearson, Inc.
- Kirisci, L., Mezzich, A. C., Reynolds, M., Tarter, R. E., & Aytaclar, S. (2009). Prospective study of the association between neurobehavior disinhibition and peer environment on illegal drug use in boys and girls. *American Journal of Drug and Alcohol Abuse*, 35, 145–150. doi:10.1080/00952990902825405
- Kirisci, L., Tarter, R., Mezzich, A., & Vanyukov, M. (2007). Developmental trajectory classes in substance use disorder etiology. *Psychology of Addictive Behaviors*, 21, 287–296. doi:10.1037/0893-164X.21.3.287
- Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment* (4th ed.). New York, NY: Oxford University Press.
- Lopez-Duran, N. L., Kuhlman, K. R., George, C., & Kovacs, M. (2013). Facial emotion expression recognition by children at familial risk for depression: High-risk boys are oversensitive to sadness. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 54, 565–574. doi:10.1111/jcpp.12005
- Luna, B., & Sweeney, J. A. (2004). The emergence of collaborative brain function: FMRI studies of the development of response inhibition. *Annals of the New York Academy of Sciences*, 1021, 296–309. doi:10.1196/annals.1308.035
- Morawetz, C., Bode, S., Baudewig, J., Kirilina, E., & Heekeren, H. R. (2015). Changes in effective connectivity between dorsal and ventral prefrontal regions moderate emotion regulation. *Cerebral Cortex*. Advance online publication. Retrieved from <http://cercor.oxfordjournals.org/content/early/2015/01/28/cercor.bhv005.long>
- Novak, S. P., & Clayton, R. R. (2001). The influence of school environment and self-regulation on transitions between stages of cigarette smoking: A multilevel analysis. *Health Psychology*, 20, 196–207. doi:10.1037/0278-6133.20.3.196
- Parsons, O. A., Tarter, R. E., & Edelberg, R. (1972). Altered motor control in chronic alcoholics. *Journal of Abnormal Psychology*, 80, 308–314. doi:10.1037/h0033740
- Pérez-Edgar, K., & Fox, N. A. (2003). Individual differences in children's performance during an emotional Stroop task: A behavioral and electrophysiological study. *Brain and Cognition*, 52, 33–51. doi:10.1016/S0278-2626(03)00007-1
- Porteus, S. D. (1965). *Porteus Maze Tests: Fifty years' application*. Palo Alto, CA: Pacific Books.
- Rao, U., & Chen, L. A. (2008). Neurobiological and psychosocial processes associated with depressive and substance-related disorders in adolescents. *Current Drug Abuse Reviews*, 1, 68–80. doi:10.2174/1874473710801010068

- Richter, L., & Johnson, P. B. (2001). Current methods of assessing substance use: A review of strengths, problems, and developments. *Journal of Drug Issues, 31*, 809–832. doi:10.1177/002204260103100401
- Sagar, K. A., Dahlgren, M. K., Gönenç, A., Racine, M. T., Dreman, M. W., & Gruber, S. A. (2015). The impact of initiation: Early onset marijuana smokers demonstrate altered Stroop performance and brain activation. *Developmental Cognitive Neuroscience, 16*, 84–92. doi: 10.1016/j.dcn.2015.03.003
- Schmidt, M. (2004). *Rey Auditory Verbal Learning Test: A handbook*. Los Angeles, CA: Western Psychological Services.
- Schneider, W., & Detweiler, M. (1987). A connectionist/control architecture for working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 21, pp. 54–119). New York, NY: Academic Press.
- Shad, M. U., Bidesi, A. S., Chen, L. A., Thomas, B. P., Ernst, M., & Rao, U. (2011). Neurobiology of decision-making in adolescents. *Behavioural Brain Research, 217*, 67–76. doi:10.1016/j.bbr.2010.09.033
- Silveri, M. M., Tzilos, G. K., Pimentel, P. J., & Yurgelun-Todd, D. A. (2004). Trajectories of adolescent emotional and cognitive development: Effects of sex and risk for drug use. *Annals of the New York Academy of Sciences, 1021*, 363–370. doi:10.1196/annals.1308.046
- Simons, J. S., & Carey, K. B. (2002). Risk and vulnerability for marijuana use problems: The role of affect dysregulation. *Psychology of Addictive Behaviors, 16*, 72–75. doi:10.1037/0893-164X.16.1.72
- Substance Abuse and Mental Health Services Administration. (2013). *Results from the 2012 National Survey on Drug Use and Health: Summary of National Findings* (Vol. Series H-46, HHS Publication No. (SMA) 13-4795). Rockville, MD: Author.
- Thames, A. D., Arbid, N., & Sayegh, P. (2014). Cannabis use and neurocognitive functioning in a non-clinical sample of users. *Addictive Behaviors, 39*, 994–999. doi:10.1016/j.addbeh.2014.01.019
- Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., . . . Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research, 168*, 242–249. doi:10.1016/j.psychres.2008.05.006
- Uekermann, J., Daum, I., Schlebusch, P., & Trenckmann, U. (2005). Processing of affective stimuli in alcoholism. *Cortex, 41*, 189–194. doi:10.1016/S0010-9452(08)70893-1
- Whitlow, C. T., Liguori, A., Livengood, L. B., Hart, S. L., Mussat-Whitlow, B. J., Lamborn, C. M., . . . Porrino, L. J. (2004). Long-term heavy marijuana users make costly decisions on a gambling task. *Drug and Alcohol Dependence, 76*, 107–111. doi:10.1016/j.drugalcdep.2004.04.009