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From individual motivation to substance use initiation: A longitudinal cohort study assessing the associations between reward sensitivity and subsequent risk of substance use initiation among US adolescents

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ABSTRACT

Background: Substance use in youth remains a pressing problem in the United States. Existing studies have shown the importance of neuropathways responsible for affective response and reward motivation in adolescents' substance use initiation and maintenance. However, limited observational studies have explored the relationship between aspects of behavioral motivation traits and the likelihood of substance use initiation in adolescents. In this prospective cohort study, we assessed the associations between behavioral motivation traits based on the Behavioral Inhibition and Approach Systems (BIS-BAS) Scale and substance use initiation using data from the Adolescent Brain Cognitive Development (ABCD) study.

Method: In the 9216 eligible sample population, we assessed the associations between mean Behavioral Inhibition System (BIS) / Behavioral Approach System (BAS) scores measured at year 2 of the ABCD study and substance use initiation at year 3 of the ABCD study using multivariable logistic regressions adjusting for ABCD study site, sampling weights, as well as sociodemographic characteristics.

Results: We found that higher BIS mean score was associated with higher odds of initiating substance use at year 3 (AOR=1.20, 95 % CI: 1.03, 1.40). Out of three BAS measure categories, only BAS Fun-seeking mean score was positively associated with higher odds of initiating substance use at year 3 (AOR=1.23, 95 % CI: 1.07, 1.43).

Conclusion: Our study showed that inhibitory and fun-seeking behavioral tendencies are associated with an increased likelihood of substance use initiation in adolescents. Our findings suggest a potential pathway linking emotional traits to early substance initiation in adolescents.

1. Introduction

Substance use, including alcohol, cannabis and tobacco product use, remains a pressing problem among adolescents in the United States (Volkow et al., 2018; Miech et al., 2023). Based on the Monitoring the Future 2022 survey on adolescent drug use in the United States, about 32 % of the 12th graders have used illicit drugs (Miech et al., 2023). Additionally, about 50 % of substance use initiation occurred during adolescence (Hamidullah et al., 2020). Adolescence is a developmental period characterized by substantial neurodevelopmental changes within brain reward learning and motivational systems, which lead to adolescents' increased likelihood to pursue risk-taking, novelty, and sensation-seeking behaviors (Hamidullah et al., 2020; Ernst and Luciana, 2015; Gladwin et al., 2011). Specifically, neuroimaging studies and theories such as incentive sensitization have suggested the importance of dopaminergic pathways, the primary neural pathway responsible for affect and reward-related motivation, in shaping the neurobiology of addiction (Hamidullah et al., 2020; Ernst and Luciana, 2015; Tervo-Clemmens et al., 2020; Schneider et al., 2012). In addition, evidence has shown that dopaminergic system activity peaks during adolescence and such alteration in the dopaminergic system might be responsible for the heightened levels of risk-taking behavior in adolescents (Ernst and

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Luciana, 2015; Hammond et al., 2014). However, limited number of epidemiologic studies have explored how different aspects of motivation and reward sensitivity are correlated with the risk of substance initiation among adolescents.

The Behavioral Inhibition and Approach Systems (BIS-BAS) Scales grounded in Gray's reinforcement sensitivity theory of personality is an excellent tool to provide a deeper understanding of how different aspects of affect regulation and motivation contribute to substance use among adolescents (Brown and Revelle, 2021:; Colder and O'Connor, 2004). Some studies have investigated the association between BIS-BAS measures and high-risk behaviors among adolescents and young adults (Franken and Muris, 2006; Gonçalves et al., 2022). However, extremely limited studies to date have explored whether BIS/BAS measures can be predictive of subsequent substance use initiation among adolescents. Using a large diverse national cohort of adolescents, our study aimed to explore the association between behavioral motivation traits based on the BIS-BAS scale and substance use initiation among adolescents. Findings from this study will shed light on potential mechanistic hypotheses linking different neural pathways to subsequent substance use initiation among adolescents.

2. Methods

2.1. Study population and eligibility criteria

The Adolescent Brain Cognitive Development (ABCD) study is a multi-center cohort study that enrolled 11,875 children at baseline from 21 recruitment sites across the U.S (Karcher and Barch, 2021). At baseline (2016 – 2018), children were between age 9 and 10 (Karcher and Barch, 2021). It is the largest study in the U.S. designed to better understand the development of physical, as well as mental health outcomes among children and adolescents (Karcher and Barch, 2021). Study participants were initially recruited through public schools and sampled using multi-stage probability sampling across the entire U.S. (Karcher and Barch, 2021). All study participants were invited to complete the interviews at baseline (2016 – 2018) and then followed up annually (Heeringa and Berglund, 2020; Garavan et al., 2018).

At baseline, participants were asked to report individual and familial socio-demographic characteristics. At each year of the follow-up study visit, youth participants were invited to complete a comprehensive set of behavioral and mental health outcome surveys, which include substance use survey (Lisdahl et al., 2021) and Modified BIS-BAS scale for behavioral motivation traits. At year 2, 10,414 individuals completed the modified BIS-BAS survey. Eligible study participants include those that had complete socio-demographic information, study sampling information, and had completed both BIS-BAS survey at year 2 and substance use behavior survey at year 3. Out of the 10414, we additionally excluded 1198 individuals with missing information on substance use initiation at year 3 and ABCD study sampling weights. To assess the association between individual behavioral motivation traits at year 2 and risk of substance use initiation at year 3, 9216 eligible study participants were included in the final analysis. The ABCD study obtained institutional review board (IRB) approval from the University of California, San Diego (UCSD) and the respective IRBs of each study site. Written assent was obtained from participants, and written informed consent was obtained from their caregivers.

2.2. Exposure of interest: Behavioral inhibition and activation systems score at year 2

The ABCD study BIS/BAS scale (Pagliaccio et al., 2016) was modified from the 1994 BIS-BAS scale (Carver and White, 1994) which includes 20 questionnaire items corresponding to one BIS subscale and three BAS subscales. The BIS subscale included 7 questionnaire items (Supplemental Material) that capture respondents' responsiveness to salient stimuli associated with punishment towards ongoing behavior. The three BAS subscales included Drive (four items that capture respondents' drive to pursue a goal-oriented behavior), Fun-seeking (four items that capture respondents' perceived enjoyment over spontaneous behaviors) and Reward responsiveness (five items that capture respondents' experience of pleasure in anticipation or experience of reward-associated stimuli) (Pagliaccio et al., 2016; Carver and White, 1994; Taubitz et al., 2015) (Supplemental Material).

In this analysis, the BIS score was calculated as the mean of the summary score of seven BIS questionnaire items. Higher BIS score indicated higher levels of inhibition towards behavior or stimuli associated with punishment. The BAS Drive (BASD) score was calculated as the mean of the summary score of the BAS Drive questionnaire items. Higher BASD indicates a higher drive to pursue goal-directed behavior. Similarly, the BAS Fun-seeking score (BASF) and BAS Reward-Responsiveness score (BASR) were calculated as the mean of the summary score of corresponding questionnaire items. Higher BASF indicates higher likelihood of seeking out novel and exciting behaviors whereas higher BASR indicates higher levels of responsiveness to rewards. When calculating the scores, all questionnaire items carried equal weights. To ensure the reliability of the modified scale used in this sample, we calculated Cronbach's α and McDonald's ω coefficient for BIS, BASD, BASF, and BASR questionnaire items respectively (Xu et al., 2021; Malkewitz et al., 2023) (BIS Cronbach' $\alpha = 0.74$, McDonald's $\omega = 0.81$; BASD Cronbach' $\alpha = 0.82$, McDonald's $\omega = 0.84$; BASF Cronbach' $\alpha = 0.75$, McDonald's $\omega = 0.78$; BASR Cronbach' $\alpha = 0.82$, McDonald's $\omega = 0.83$).

Additionally, to identify whether the imbalance between inhibition and reward motivation system measured at year 2 is associated with the likelihood of substance use initiation at year 3, we calculated BIS:BAS ratio defined as (BIS score – BAS score) / (BIS score + BAS score) where BIS score is the mean of the summary score of 7 BIS questionnaire items and BAS score is the mean of the summary score of all 13 BAS questionnaire items (Sutton and Davidson, 1997; Schutter et al., 2008; Taylor et al., 2021). Higher BIS:BAS ratio indicated higher levels of imbalance between BIS and BAS system (Taylor et al., 2021).

2.3. Outcome of Interest: Substance use initiation at year 3

At both year 2 and year 3, study participants were invited to complete the ABCD Youth Substance Use Introduction and Patterns survey (Lisdahl et al., 2021). At both waves, participants were asked if they had a sip of an alcoholic product (i.e. beer, wine or liquor including rum, vodka, gin, or whiskey); a puff from a tobacco product or electronic cigarette, Juul, vape pens, electronic-hookah, cigar or pipe; a puff or eaten any marijuana, also called pot, grass, weed or ganja. Initiation of any type of substance at either year 2 or year 3 was defined as participants having tried a sip of alcohol product, or a puff of tobacco product or a puff of marijuana (Shao et al., 2023). New initiators of any type of substance use at year 3 was identified if the respondent never used any substance at year 2 and reported having experimented with any type of substance at year 3.

2.4. Covariates of interest

Demographic information including sex, age, and race/ethnicity were collected at year 2. Household income was defined as greater or less than 75,000 U.S. dollars based on the median U.S. household income (Semega et al., 2019). Parental education was a dichotomous variable, defined as high school or less versus college or higher-level education based on reported parental education levels. (Supplemental Materials).

2.5. Statistical analyses

To assess the associations between BIS/BAS measures at year 2 and substance use initiation at year 3, multivariable logistic regression

models were used, adjusting for covariates of interest, as well as study site and ABCD study sampling weight (Gard et al., 2023). Similarly, we assessed the association between BIS:BAS ratio at year 2 and substance use initiation at year 3 using multivariable logistic regression, adjusting for covariates mentioned previously. Given limited evidence and the importance of exploring sex differences in substance use among adolescents (Carver and White, 1994; Kuhn, 2015), we further evaluated the effect modification by sex by including the interaction term in all regression analyses. If statistically significant effect modification is present, stratified analyses by sex were performed to evaluate the magnitude of effect modification. All analyses were performed in RStudio (4.1.2).

3. Results

3.1. Study population characteristics

Among 9216 eligible study participants included in this study, about 48.9 % were female, White (54.5 %), and coming from a household with a household income less than $75,000 annually (54.7 %). At year 3, the highest proportion of the study population reported having tried a sip of alcohol product (11.8 %) as compared to those that reported having tried any type of tobacco product (2.6 %) and those that reported having tried any type of marijuana product (1.1 %). Amongst all BIS/BAS mean scores, the BASR score is the highest (mean = 1.98) followed by the BIS mean score (1.24) whereas the BASD score is the lowest (mean = 0.91). (Table 1).

When comparing those that reported having tried some type of substance at year 3 versus those that reported never tried any type of substance at year 3, the proportion of female versus male remained similar. However, there are higher proportions of racial/ethnic minorities amongst those that reported never having tried any substance at year 3. A smaller number of individuals that reported having tried some type of substance at year 3 reported coming from a household with income less than $75,000 and parental education less than high school. (Table 2) When comparing the scores from the BIS-BAS scale, those that reported having tried some type of substance at year 3 had higher scores across all categories as compared to those that did not. (Table 2).

Table 1
Characteristics of Eligible Study Population Included in the Analysis.

	Eligible Study Population (N=9216) N (%)	% Adjusted for sampling weights
Female	4422 (48.0)	48.9
Race		
White	5011 (54.4)	54.5
Latino	1569 (17.0)	20.2
Black	1649 (17.9)	15.3
Asian	544 (5.9)	5.3
Native American	334 (3.6)	3.3
Other	79 (1.0)	1.4
Parental education high school or less	1367 (14.8)	17.6
Household income less than $75,000	4998 (54.2)	54.7
Have tried a sip of a sip of alcohol such as beer, wine or liquor (rum, vodka, gin, whiskey)	1098 (11.9)	11.8
Have tried a puff from a tobacco or electronic cigarette, Juul, vape pens, e-hookah, cigar or pipe	184 (1.9)	2.6
Have tried a puff or eaten any marijuana, also called pot, grass, weed or ganja	81 (1.0)	1.1
Mean (SD)		
BIS score	1.24 (0.56)	1.24 (0.01)
*BASR score	1.98 (0.63)	1.97 (0.01)
*BASF score	1.13 (0.65)	1.13 (0.01)
*BASD score	0.91 (0.69)	0.93 (0.01)
**BIS/BAS Ratio	−0.34 (0.65)	−0.34 (0.01)

*BASR Score corresponds to BAS Reward Responsiveness score; BASF Score corresponds to BAS Fun-seeking score; BASD score corresponds to BAS Drive score.
***BIS/BAS* Ratio *was calculated as (BIS mean score – BAS mean score) / (BIS mean score + BAS mean score).*

3.2. Association between BIS-BAS scale measures at year 2 and substance use initiation at year 3

Table 3 shows the associations between each BIS/BAS mean score and substance use initiation at year 3. Every unit increase in the BIS mean score is associated with 20 % higher odds of initiating substance use at year 3 (AOR=1.20, 95 % CI: 1.03, 1.40). Out of three BAS categories, only BAS Fun-seeking mean score was positively associated with higher odds of initiating substance use at year 3 (AOR=1.23, 95 % CI: 1.07, 1.43). BAS drive and BAS reward responsiveness were not associated with substance use initiation at year 3, respectively (AOR=1.12, 95 % CI: 0.98,1.27; AOR: 1.10, 95 % CI: 0.94,1.28). BIS:BAS ratio measured at year 2 was also not significantly associated with substance use initiation at year 3 (AOR=0.76, 95 % CI: 0.45, 1.25).

When evaluating the potential effect modification by sex, we did not find any effect modification by sex across all BIS-BAS scale scores. However, the effect modification by sex for the association between BIS:BAS ratio and substance use initiation was statistically significant. (Table 3) Higher BIS:BAS ratio is associated with lower odds of substance use initiation for male participants while higher BIS:BAS ratio increases the odds of substance use initiation in female participants (AOR=0.76, 95 % CI: 0.45, 1.25; AOR=1.59, 95 % CI: 0.90, 2.81).

4. Discussion

In this large sample of adolescents in the United States, we found that

Table 2
Characteristics of the Eligible Study Population by Reported Substance Use Status at Year 3 in the ABCD Study.

	Participants reported having tried any type of substance at year 3 (N=1230)	Participants reported never having tried any type of substance at year 3 (N=8021)
	% Adjusted for sampling weights	***% Adjusted for sampling weights***
Female	48.3	49.1
Race		
White	68.6	52.4
Latino	15.5	20.9
Black	8.2	16.3
Asian	2.2	5.8
Native American	3.8	3.3
Other	1.6	1.3
Parental education high school or less	11.9	18.4
Household income less than $75,000	47.2	55.8
Mean (SD)		
BIS score	1.33 (0.02)	1.22 (0.01)
BASR score	2.00 (0.02)	1.97 (0.01)
BASF score	1.28 (0.02)	1.10 (0.01)
BASD score	0.98 (0.02)	0.92 (0.01)
BIS/BAS Ratio	−0.33 (0.01)	−0.34 (0.01)

*BASR Score corresponds to BAS Reward Responsiveness score; BASF Score corresponds to BAS Fun-seeking score; BASD score corresponds to BAS Drive score.
**BIS/BAS Ratio was calculated as (BIS mean score – BAS mean score) / (BIS mean score + BAS mean score).

Table 3
Association between BIS/BAS score at Year 2 and Substance Use Initiation at Year 3 in the ABCD Study.

	Adjusted Odds Ratio (95 % Confidence Interval)	p-value for effect modification by sex
BIS* mean score	1.20 (1.03, 1.40)	0.46
BASD* mean score	1.12 (0.98, 1.27)	0.09
BASF* mean score	1.23 (1.07, 1.43)	0.32
BASR* mean score	1.10 (0.94, 1.28)	0.12
BIS:BAS ratio	1.14 (0.77, 1.68)	*0.04*
Stratified Analysis	**Adjusted Odds Ratio (95 % Confidence Interval) Male**	**Adjusted Odds Ratio (95 % Confidence Interval) Female**
BIS:BAS Ratio	0.76 (0.45, 1.25)	1.59 (0.90, 2.81)

*BASR: BAS Reward Responsiveness; BASF: BAS Fun-seeking; BASD: BAS Drive.
**BIS/BAS Ratio was calculated as (BIS mean score – BAS mean score) / (BIS mean score + BAS mean score);
All Models adjusted for sociodemographic characteristics, ABCD study site ID and sampling weights.

higher BIS score and BAS Fun-seeking score were significantly associated with an increased risk of initiating substance use one year later. In addition, the effect of the imbalance between behavioral inhibition and activation systems on the risk of substance use initiation one year later differs by sex.

Findings from our study were consistent with various neuroimaging and psychological studies showing a link between BIS/BAS levels and substance use, especially among adolescents (Taylor et al., 2021; Rádosi et al., 2021; Franken and Muris, 2006; Rømer Thomsen et al., 2018). Interestingly, our study's finding is consistent with one study focusing on the link between BIS/BAS scale and cannabis use in adults, which also show that an imbalance in BIS/BAS and BAS fun-seeking score are linked with cannabis initiation and maintenance among adults (Taylor et al., 2021). In terms of Behavioral Approach System, higher BAS reward responsiveness score and BAS drive score jointly reflect an individual's sensitivity to rewards (Taubitz et al., 2015), which are often associated with reward seeking behavior such as substance use as a result of higher engagement in dopaminergic reward circuit (Rádosi et al., 2021). Nonetheless, we did not find associations between BASR/BASD scores and the likelihood of adolescent substance use initiation. It could potentially be explained by the young age of study population. In addition, one study has shown that higher BASR score indicates higher resilience for maladaptive psychological function and promotes higher positive psychological outcomes, which might explain our null findings (Taubitz et al., 2015). While a majority of studies on adolescent substance use have been focused on the BAS system, limited studies have focused on the role of behavioral inhibition system and substance use in adolescents. Our study's finding did resonate with prior studies also showing that higher BIS score was associated with an increased likelihood of substance use (Taylor et al., 2021; Rádosi et al., 2021). High levels of activity in behavioral inhibition system are linked to increased levels of negative emotions (Thake and Zelenski, 2013) as a result of increased activation in amygdala, which can result in higher levels of anxiety (Stein et al., 2007). Our finding suggests the possibility that higher BIS score as a result of increased amygdala activity can potentially lead to higher levels of anxiety, which has been shown to be an important precursor to substance use in adolescents (Ernst and Luciana, 2015; Marmorstein et al., 2010; Elsayed et al., 2018). Although we found associations between BIS/BAS scores with substance use initiation separately, we did not find a statistically significant association between BIS/BAS imbalance measured by BIS:BAS ratio and substance use initiation in adolescents. However, we did find the presence of effect modification by sex, suggesting the likely impact of sex difference on the effect of BIS/BAS imbalance on substance initiation.

Our study has several key strengths. First, to our knowledge, this is one of the first epidemiologic studies that comprehensively evaluated the associations between different aspects of BIS/BAS scale and substance use initiation in a nationally large sample of adolescents. In addition, the prospective cohort study design and the comprehensive data from the ABCD study allowed us to explore what traits among adolescents are associated with increased likelihood of trying some type of substance one year later. However, there are several limitations that need to be acknowledged as well. First, due to the self-reported nature of the questionnaire, adolescents might be more likely to deny their substance use experience at an earlier age, which might lead to outcome misclassification. To address this concern, we ensured that individuals are new initiators of substance by making sure they have never reported any substance use in prior years' surveys. Second, given that the exposure and outcome measures were only one year apart, we might not have been able to detect the association between certain aspects of exposure measures due to the short duration of the study follow-up. It would be important to confirm the findings in future studies once new study data are released in the future. Lastly, residual confounding remains an issue (al'Absi, 2009).

To conclude, our study showed that behavioral motivation traits including inhibitory behavioral traits and pursuing fun-seeking behaviors are associated with likelihood of substance use initiation in adolescents. Additionally, higher BIS score and higher BAS fun-seeking score are associated with an increased likelihood of initiating substance one year later in this study sample. Findings from our study provide important implications for future mechanistic studies exploring psychopathology and neuropathways that could be associated with early initiation of substance use in adolescents. More importantly, our finding suggests a potential pathway linking negative emotions to an increased likelihood of early substance initiation in adolescents. Future studies could explore the potential mediating pathway linking BIS to substance use through presence of stress or anxiety in adolescents. Additionally, future research could utilize the upcoming release of the updated ABCD study data to conduct a longitudinal study assessing the association between BIS/BAS measures and substance use initiation with longer study follow-up duration.

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CRediT authorship contribution statement

Iris Y. Shao: . **Abubakr A.A. Al-Shoaibi:** Writing – review & editing, Formal analysis. **Kyle T. Ganson:** . **Alexander Testa:** Writing – review & editing. **Orsolya Kiss:** Writing – review & editing. **Jinbo He:** Writing – review & editing. **Fiona C. Baker:** . **Jason M. Nagata:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Author agreement

All authors have seen and approved the final version of the manuscript being submitted. They warrant that the article is the authors' original work, hasn't received prior publication and isn't under consideration for publication elsewhere.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.addbeh.2024.108162.

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