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Validating a brief screening measure for early-onset substance use during adolescence in a diverse, nationwide birth cohort

William E. Pelham III [a,*], William R. Corbin [b], Madeline H. Meier [b]

[a] Center for Human Development, University of California, San Diego, United States
[b] Department of Psychology, Arizona State University, United States

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ABSTRACT

The Loeber Risk Score (LRS) was developed to predict early-onset cannabis use in adolescence from late childhood, facilitating early identification. However, the LRS was developed in non-representative historical samples, leaving uncertain its generalizability to children/adolescents across the U.S. today. We externally validated the LRS in a diverse, nationwide cohort ($N = 4{,}898$) weighted to the composition of the U.S. Census. Participants in 20 cities completed assessments when youth were approximately 5, 9, and 15 years old. Parents completed the LRS at the age ~5 and ~9 interviews. At the age ~15 interview, youth reported on the onset of alcohol/drug use before age 15, monthly drinking/binge drinking at ages 14–16, and use of cannabis multiple times per month at ages 14–16. First, we validated the LRS measured at age ~9. Area under the receiver operating curve was 0.62 for onset of cannabis use before age 15, 0.68 for onset of cigarette use before age 15, and 0.62 for use of cannabis multiple times per month at ages 14–16. For drinking outcomes, LRS performance could not be distinguished from chance prediction. The recommended screening cutoff of LRS ≥ 2 identified 24% of children, among whom early-onset cannabis/cigarette use outcomes occurred 1.4–2.2 times more frequently than the general population. The LRS' performance did not vary significantly by sex, race, or ethnicity. When the LRS was measured at age ~5, AUROC was significantly lower for some outcomes. Together, findings support the LRS measure as a potential tool for identifying children in early or late childhood at risk of early-onset drug use in adolescence.

1. Introduction

Early onset of alcohol/drug use during adolescence is associated with increased risk of substance use disorder in adulthood (Grant & Dawson, 1997; Han et al., 2019). Accordingly, there is interest in identifying high-risk children/adolescents *before* they initiate or escalate substance involvement and linking them to preventive services that can promote healthier developmental trajectories of substance use (Dodge, 2020; Faggiano et al., 2008; Masten et al., 2008; O'Connell et al., 2009; Van Ryzin et al., 2016). However, the task of screening children to identify those at prospective risk of substance use in adolescence has received little attention (Meier et al., 2016; Pilowsky & Wu, 2013; US Preventive Services Task Force, 2018, 2020; Winters et al., 2019).

Only one screening instrument is available that purports to identify high-risk youth before they initiate substance use: the Loeber Risk Score (LRS). The LRS was originally developed to inform recruitment of a large, multisite cohort to study adolescent substance use (Loeber et al., 2018). Loeber et al. used data from four existing longitudinal studies to develop a five-item, parent-report measure to identify children ages 9–11 years old who were at risk of establishing regular (≥5/6 times per year) cannabis use by ages 14–16 years old. The five items assess two domains of risk factors: child externalizing problems (4 items) and caregiver smoking (1 item). In holdout data from the development samples, the LRS had modest accuracy in predicting early cannabis use. Area under the received operating characteristic curve (AUROC) ranged from 0.59 to 0.69, indicating potential for the LRS to inform high-risk research designs or targeted prevention.

The LRS filled an important gap, but its utility can be improved. First, the LRS was designed and evaluated in historical, geographically limited, unrepresentative samples of primarily high-risk youth (Ahonen et al., 2021; Hipwell et al., 2002; Tarter & Vanyukov, 2001; Zucker et al., 1996). Since the 1990 s, when the first of the Loeber et al. cohorts were teens, there have been substantial changes in the prevalence, social norms, and perceived harms of alcohol and drug classes (Miech et al.,

* Corresponding author at: Center for Human Development, University of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093, United States.
E-mail address: wpelham@ucsd.edu (W.E. Pelham).

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2020). The Loeber et al. cohorts were recruited in western Pennsylvania or central Michigan, yet there is significant geographic variability in rates and patterns of adolescent substance use (Hawkins et al., 2004; Moss et al., 2018). Finally, high-risks samples that have selected participants on the basis of pre-existing risk factors (e.g., parent substance use disorder, conduct problems) may exhibit different patterns of predictive utility for those risk factors due to restriction of range (Sackett & Yang, 2000). Thus, it remains unknown how the LRS will generalize to children/adolescents across the U.S. today.

Second, the LRS validation focused on cannabis use, though it may also be useful for predicting onset of other substances of interest (e.g., alcohol, cigarettes) or onset of *any* alcohol/drug use, collapsing across categories. Comparison of reviews of risk factors for early onset of alcohol (Donovan, 2004), cannabis (Guxens et al., 2007), and cigarette use (Wellman et al., 2016) reveals substantial overlap, including among the risk factors measured in the LRS (i.e., child externalizing problems and parent smoking), so the LRS may predict onset of other drugs and alcohol.

Third, no study has examined how the LRS performs across racial/ethnic groups. There is significant race- and ethnicity-related variability in adolescent substance use (Delva et al., 2019; Shih et al., 2010) as well as in the risk factors measured in the LRS items. For example, rates of cigarette smoking are 1.8–2.2 times higher among U.S. adults identifying as White/Black versus Hispanic/Asian (Center for Disease Control and Prevention, 2021). To promote health equity (Teresi et al., 2006), it is important to verify that such differences do not result in varying LRS performance when predicting early substance use in different racial/ethnic groups.

Fourth, no study has examined how the LRS performs when administered in early childhood, though identification at a younger age may be preferable for prevention. Targets for prevention may be more readily modified when children are younger and less established in their patterns of behavior and relationships with parents and peers (Dodge, 2020). However, outcomes typically become more predictable as they become more proximal, so it may be harder to identify those at risk of early substance use from an assessment earlier in childhood (Dodge, 2020).

2. Current study

After development of a screening measure, the next step is external validation in a new sample (Steyerberg et al., 2013; Steyerberg & Harrell, 2016). The current study subjected the LRS to external validation in a diverse, nationwide birth cohort of 4,898 youth in 20 cities: the Fragile Families and Child Wellbeing Study (FFCWS; Reichman et al., 2001). To address the limitations above, we characterized predictive performance across several alcohol/drug use outcomes and tested for differences by youth age, sex, race, and ethnicity. As the risk factors measured in the LRS are shared across different substances, we hypothesized that the LRS would display better-than-chance performance in predicting each alcohol/drug use outcome that was tested. Absent previous findings to suggest otherwise, we hypothesized that LRS performance would not differ by youth sex, race, or ethnicity. As prediction is typically easier over shorter time intervals between predictor and outcome, we hypothesized that LRS performance would be superior when the LRS was measured in late vs. early childhood. The goal of these analyses was to evaluate the usefulness of the LRS for identifying children at risk of early substance use.

3. Material and methods

3.1. Sample

FFCWS is a cohort of 4,898 children born between 1998 and 2000 in 20 cities across the U.S. Families were recruited at the hospital immediately following birth under stratified random sampling (Center for Research on Child Wellbeing, 2008; Kennedy & Gelman, 2018; Reichman et al., 2001). Births to unmarried parents were intentionally oversampled, which we address in our analysis via weighting. Before weighting, 48% of children were female. 24% of mothers were married, 31% were White, 50% were Black, and 27% were Hispanic. 65% of mothers had graduated high school and 11% had a college/graduate degree. 36% of families were below the federal poverty line.

The current study draws data from longitudinal assessments near child ages 5, 9, and 15 years. Mean ages at these assessments were 5.2 years (range = 4.8–6.0), 9.4 years (range = 8.7–11), and 15.6 years (range = 14.4–18.8) respectively. Table 1 reports descriptive statistics for all study variables.

3.2. Loeber risk score

As described in Loeber et al. (2018), there were minor variations in item wording across the four longitudinal samples they examined. In the current study, we used the item wording and response options that was common across most of the Loeber et al. (2018) samples, aiming to conduct a direct replication of their risk score in a new sample. Table S1 reproduces the exact item wording, response options, and scoring

Table 1
Descriptive Statistics for Study Variables.

Variable	Wave of Measurement	*N*	Descriptive Statistics
			Percentage selecting item response 0 / 1 / 2:
LRS item 1: Child destroys things belonging to his or her family or others	Age 5	2,915	81 % / 16% / 2 %
	Age 9	3,190	87 % / 12 % / 1 %
LRS item 2: Child is disobedient at school	Age 5	2,885	76 % / 22 % / 2 %
	Age 9	3,166	78 % / 21 % / 1 %
LRS item 3: Child lies or cheats	Age 5	2,913	98 % / 2 % / 0 %
	Age 9	3,196	98 % / 2 % / 0 %
LRS item 4: Child steals outside the home	Age 5	2,915	75 % / 23 % / 1 %
	Age 9	3,192	74 % / 25 % / 1 %
			Percentage endorsing:
LRS item 5: Mother has smoked in the past month	Age 5	2,919	28 %
	Age 9	3,438	28 %
Used any substance before age 15	Age 15	2,934	23 %
Used alcohol before age 15	Age 15	2,913	15 %
Used cannabis before age 15	Age 15	2,915	14 %
Used cigarettes before age 15	Age 15	2,890	5 %
Drank alcohol monthly during past year at ages 14–16	Age 15	3,121	10 %
Binge drank monthly during past year at ages 14–16	Age 15	3,120	3 %
Used cannabis multiple times per month during past year at ages 14–16	Age 15	3,115	5 %

Note. *N* = number of observations, LRS = Loeber Risk Score. Age is in years. For LRS items 1–4, values indicate the percentage of the sample responding 0 (*not true*), 1 (*somewhat true*), or 2 (*very true*). For remaining variables, values indicate the percentage of the sample endorsing the variable. Descriptive statistics are based on the weighted data. Among those reporting any substance use before age 15, the most common endorsements were for alcohol (53%) or cannabis use (77%). Youth substance use outcomes "before age 15" and "at ages 14–16" were measured at the same age ~15 assessment. The "before age 15" outcomes could be missing if the youth had not initiated substance use but had not yet reached their 15th birthday as of the age ~15 assessment. The "at ages 14–16" outcomes included all youth who had reached their 14th birthday but not yet reached their 17th birthday as of the age ~15 assessment.

algorithm used in FFCWS. At ages ~5 and ~9 years, caregivers completed interviews from which we drew the items comprising the LRS. Four LRS items assess child externalizing problems and one LRS item assesses parent smoking. For the first four LRS items, the primary caregiver (97% mothers) rated the following behaviors on a scale from 0 (*not true*) to 2 (*very true*) (Achenbach, 1992; Achenbach & Rescorla, 2001): child destroys things that belong to his/her family or others; child is disobedient at school; child lies or cheats; child steals outside the home. For the fifth LRS item, the primary caregiver reported whether they had smoked any cigarettes in the past month, collapsed to a scale of 0 (*no*) or 1 (*yes*). Following Loeber et al. (D. Clark, personal communication, January 14, 2020), the LRS was the sum of these five items, ranging from 0 to 9. The mean LRS equaled 1.0 ($SD = 1.2$) at age 5 and 1.0 ($SD = 1.2$) at age 9. Loeber et al. (2018) recommended a cutoff of LRS ≥ 2 for identifying children at risk.

3.3. Alcohol/drug use outcomes

We examined two types of outcomes: early age of onset and early establishment of regular use (Kuntsche et al., 2016).

3.3.1. Early age of onset

At age ~15 years, teens were privately interviewed by a study staff member, typically by phone. Teens answered a series of questions about alcohol/drug use modeled on those in existing national surveillance studies (Miech et al., 2020). First, they were asked gating questions: (1) Have you had a drink of beer, wine, or liquor—not just a sip or a taste of someone else's drink – more than two or three times in your life when you were not with your parents?, (2) Have you ever tried marijuana?, (3) Have you ever smoked an entire cigarette?, (4) Besides marijuana, have you ever tried any other illicit drug?, and (5) Have you ever taken any prescription drugs that were not prescribed for you or that you took only for the experience or feeling they caused?. If the teen indicated having used, follow-up questions determined the age of first use. Following published literature (Donovan, 2004; Donovan & Molina, 2011; Hayatbakhsh et al., 2008), we defined early onset of use as occurring before the 15th birthday. Participants met this criterion at the following rates: alcohol (15%), cannabis (14%), cigarettes (5%), any substance pooling across categories (23%).

3.3.2. Early establishment of regular use

Additional follow-up questions assessed the past-year frequency of drinking, binge drinking ("five or more drinks in a row"), and cannabis use. Given the response scales for each item, we created indicators of whether teens met or exceeded the following frequency of use: drank monthly (10%), binge drank monthly (3%), or used cannabis multiple times (>1 day) per month (5%).[1]

3.4. Analytic plan

Caregiver-reported LRS at ages ~5 and ~9 were used to predict youth self-reported substance use outcomes at age ~15. Analyses were conducted in R v4.1.2 (R Core Team, 2021). A total of 2,878 caregivers completed the LRS at age 5 and 3,141 completed it at age 9.[2] A total of 3,243 teens reported on their substance use at age 15. To enhance generalizability, participants in every analysis were weighted (Lumley, 2003) to reflect families in the U.S. Census' American Community Survey (ACS; Ruggles et al., 2021) on the following characteristics: youth's sex, race, and ethnicity; mother's education, labor force status, and marital status. Attrition analyses indicated that families with mothers born outside the U.S. were more likely to be missing at follow-up waves, so mother's nativity was added to the weights model (Seaman & White, 2013). Table S2 compares the unweighted and weighted data—all subsequent estimates in this manuscript were based on weighted data. See the supplementary material for further details about weighting and attrition analyses.

Table 2 lists the metrics by which we measured the LRS performance, how they were calculated, and how they can be interpreted. To characterize the LRS' overall performance, we computed area under the receiver operating characteristic curve (AUROC) (Hanley & McNeil, 1982). AUROC ranges from 0 to 1 and measures the LRS' ability to discriminate cases from non-cases (AUROC = 0.50 indicates chance prediction). We then estimated the LRS' positive and negative predictive value (PPV/NPV), accuracy, sensitivity, and specificity at screening thresholds of ≥ 1, ≥ 2, ≥ 3, ≥ 4, and ≥ 5. We focus interpretation on the predictive value metrics (PPV/NPV), which tell us how likely the LRS-based prediction for a given youth is likely to come true (Harrell & Slaughter, 2018).

We next estimated performance metrics separately for subsamples defined by sex (male vs. females), race (white vs. black), ethnicity (Hispanic vs. non-Hispanic), and child age (5 years vs. 9 years). To determine if performance varied significantly, we estimated the difference in AUROC between each pair of groups.

For AUROC and comparisons of AUROC, we estimated 95% confidence intervals using the nonparametric basic bootstrap ($B = 500$) (Davison & Hinkley, 1997). For all other performance metrics, confidence intervals were constructed using the logit method (Lumley, 2003).

4. Results

We first evaluated the LRS when completed at age ~9 years, to match when the LRS was completed in the Loeber et al. (2018) samples. Fig. 1, Panel A graphs the estimated AUROCs and 95% CIs. At age 9, the LRS had an AUROC significantly ($ps < .05$) better than chance when predicting use of cannabis (AUROC = 0.62, 95% CI = [0.57, 0.67]), cigarettes (AUROC = 0.68; 95% CI = [0.60, 0.77]), or any substance (AUROC = 0.59, 95% CI = [0.55, 0.63]) before age 15, or when predicting use of cannabis multiple times per month at ages 14–16 (AUROC = 0.62; 95% CI = [0.55, 0.69]). AUROCs were lower for alcohol outcomes (AUROC = 0.52–0.54) and not significantly better than chance.

Table 3 reports the predictive performance of the LRS at age ~9 years across screening thresholds. Among potential thresholds, Loeber et al.'s recommended cutoff of LRS ≥ 2 was sensible for all outcomes, selecting 24% of the sample and yielding classification accuracy from 0.69 to 0.76. As expected given the base rates, NPVs (0.80–0.97) were considerably greater than PPVs (0.04–0.33). The use of more stringent cutoffs that selected fewer participants (e.g., LRS ≥ 5) yielded improvements in PPV.

For the LRS at age ~9 years, there were no statistically significant differences in AUROC in males vs. females, Black vs. White youth, and Hispanic vs. Non-Hispanic youth, for any alcohol/drug use outcome. The magnitude of sex, racial, and ethnic group differences in AUROC was small—typically less than 0.07 and never exceeding 0.13 (Table S3).

When comparing the LRS at age 5 and age 9 years, the AUROC was significantly ($ps < .05$) better at age 9 for three outcomes: use of cannabis before age 15, use of any substance before age 15, or use of cannabis multiple times per month at ages 14–16 (Table S3). Fig. 1, Panel B contrasts AUROCs at age 5 vs. age 9 for these three outcomes.

[1] Of those using cannabis multiple times per month, 62% were using on a weekly basis. Of those drinking or binge drinking on a monthly basis, almost none did so on a weekly basis ($ns \leq 7$).

[2] The LRS items were completed by the primary caregiver. The structure of the FFCWS surveys changed between the age ~5 and age ~9 assessments. At the age ~5 assessment, the primary caregiver surveys were completed after the mother and father surveys, as part of the in-home study. At the age ~9 assessment, the primary caregiver surveys were completed first, before the mother and father surveys, as part of the core study. This change in protocol resulted in greater sample size for the LRS at age 9 than age 5.

Table 2
Metrics of Predictive Performance.

Metric	Range	Formula	Interpretation
AUROC	0–1	See Hanley & McNeil (1982)	Probability that given a randomly selected case that did display early-onset substance use outcome and a randomly selected case that did not display early-onset use outcome, the case that did display early-onset use will be ranked higher on the LRS
Proportion selected	0–1	$\#true\ positives + \#false\ positives$	Proportion of youth who are classified as "positives" in the screening (i.e., predicted to display early-onset substance use)
PPV	0–1	$\frac{\#true\ positives}{\#true\ positives + \#false\ positives}$	Probability that LRS-based prediction that youth will display early-onset substance use outcome is correct
NPV	0–1	$\frac{\#true\ negatives}{\#true\ negatives + \#false\ negatives}$	Probability that LRS-based prediction that youth will not display early-onset substance use outcome is correct
Accuracy	0–1	$\frac{\#true\ positives + \#true\ negatives}{\#total\ youth}$	Probability that LRS-based prediction of whether youth will display early-onset substance use outcome is correct
Sensitivity	0–1	$\frac{\#true\ positives}{\#true\ positives + \#false\ negatives}$	Proportion of youth who did display early-onset substance use outcome who were predicted to do so by LRS
Specificity	0–1	$\frac{\#true\ negatives}{\#true\ negatives + \#false\ positives}$	Proportion of youth who did not display early-onset substance use outcome who were predicted to not do so by LRS

Note. AUROC = area under the receiver operating characteristic curve, PPV = positive predictive value, NPV = negative predictive value, Range = range of possible values, LRS = Loeber Risk Score. "True positives" refers to the number of participants with LRS ≥ screening threshold who go on to display the early-onset substance use outcome. "False positives" refers to the number of participants with LRS ≥ screening threshold who go on to display the early-onset substance use outcome. "True negatives" refers to the number of participants with LRS < screening threshold who go on to *not* display the early-onset substance use outcome. "False negatives" refers to the number of participants with LRS < screening threshold who go on to display the early-onset substance use outcome.

5. Discussion

In a large, diverse, nationwide birth cohort, we externally validated a brief screening measure for predicting early-onset alcohol/drug use: the Loeber Risk Score. For cannabis and cigarettes, the LRS discriminated early/regular users during adolescence significantly better than chance. Predictive performance was modest, as in Loeber et al. (2018).

To synthesize findings, Table 4 compares the estimated AUROCs in this study and the samples used by Loeber et al. (2018). Outcomes were not measured identically in this study versus Loeber et al. (2018), precluding a direct comparison of the estimates. However, our estimates of AUROC when predicting cannabis use before age 15 (0.62) or multiple times per month during the past year at ages 14–16 (0.62) were both within the range of AUROCs obtained by Loeber et al. when predicting cannabis use ≥ 5 times during the past year at ages 14–16 (0.59–0.69). Thus, our data suggest the LRS generalizes to children/adolescents across the U.S. today when predicting early establishment of regular cannabis use.

Although the LRS was developed to predict cannabis use (Loeber et al., 2018), it performed better when predicting early onset of cigarette use (AUROC = 0.68) than early onset of cannabis use (AUROC = 0.62). While similar performance might be expected based on shared risk factors for early nicotine vs. cannabis use (Hawkins et al., 1992), superior performance may arise from the LRS' inclusion of an item assessing caregiver smoking. Whether a caregiver smokes may proxy for greater nicotine-specific genetic risk, the availability of cigarettes, or the modeling of cigarette smoking.

The LRS performed worse when predicting drinking outcomes and in no instance did it discriminate significantly better than chance. The measure was initially developed to predict cannabis use—perhaps the externalizing behavior items that were selected are less appropriate or insufficient for predicting alcohol use, which was more common (i.e., normative) than drug use in this sample.

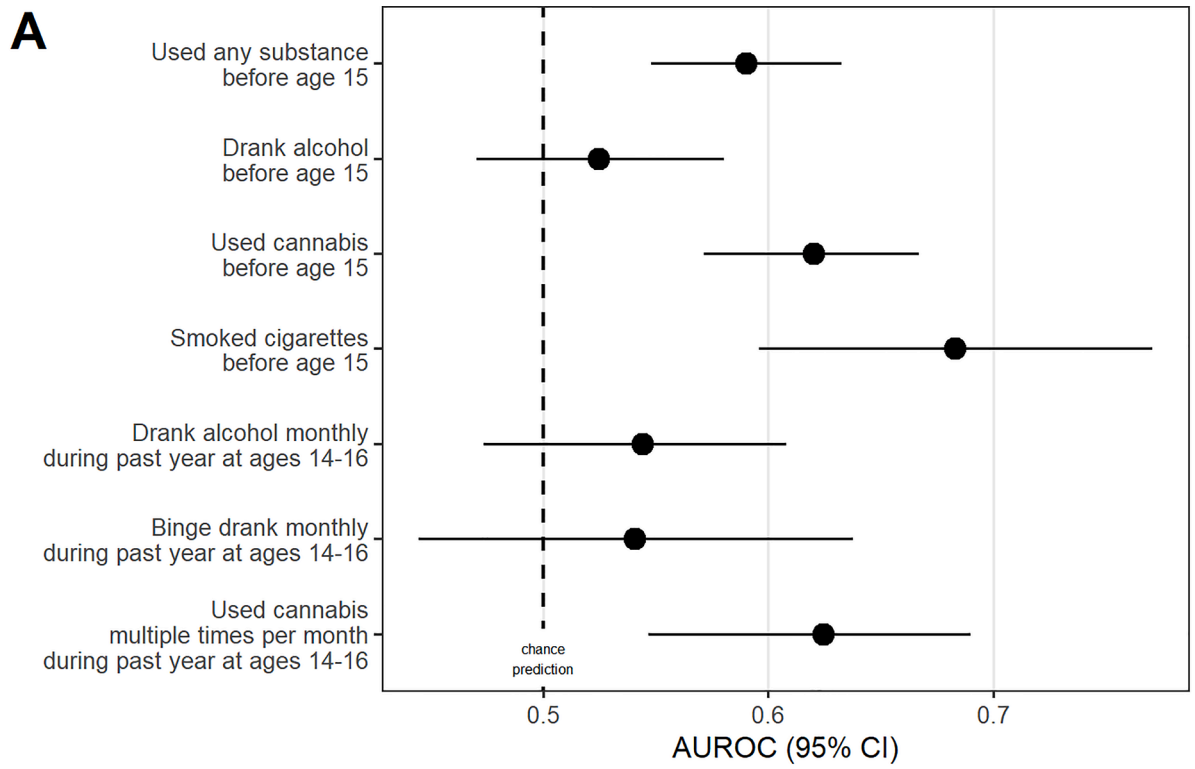
Most targeted prevention programs target risk factors that are shared across substances— few programs focus narrowly on reducing use of a single substance (Van Ryzin et al., 2016). Thus, when identifying children to receive these services, users may wish to screen for early-onset use of *any* alcohol or drug class. The LRS significantly predicted early-onset use of any alcohol/drugs, with the AUROC (0.59) being lower than the AUROCs for cannabis/cigarettes and higher than the AUROCs for alcohol.

We did not find evidence that the LRS performance varied in males vs. females, Black vs. White youth, or Hispanic vs. Non-Hispanic youth, supporting its use in those subpopulations. We found some evidence that LRS performance was worse when completed in early childhood (age 5) instead of late childhood (age 9). The discrepancy was modest when predicting use of any substance (ΔAUROC = 0.05) or cannabis (ΔAUROC = 0.08) before age 15, but larger when predicting use of cannabis multiple times per month (ΔAUROC = 0.18). Thus, waiting to screen in late (vs. early) childhood appears to modestly improve the accuracy of some predictions (Augustyn et al., 2020; Dodge, 2020).

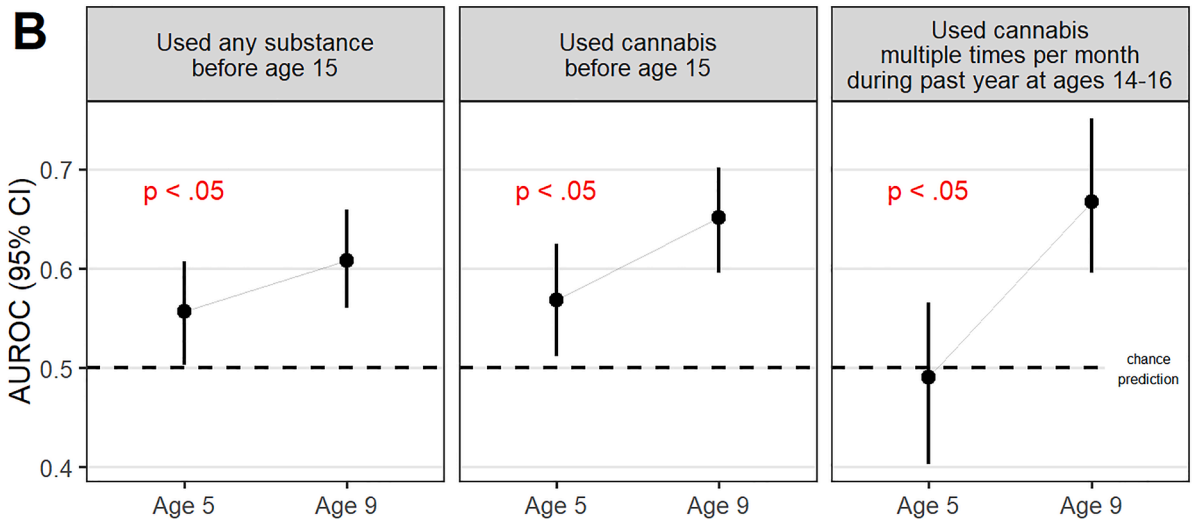
5.1. Potential applications of the LRS

Loeber et al. (2018) developed the LRS to inform recruitment of high-risk youth for a longitudinal cohort study (Volkow et al., 2018) and cautioned that the measure "was not designed to be applicable to guiding preventive or clinical interventions" (p. 29). However, consideration of findings across their study and ours suggests the LRS could have utility for both high-risk research designs and targeted interventions. Although the LRS' predictive performance is modest, we are aware of no other validated method for identifying children at risk of early-onset substance use: thus, the relevant comparison for the LRS is to no screening procedure at all. When compared to an unscreened group (i.e., random selection), we estimated a group of children selected with LRS ≥ 2 will exhibit (a) 1.4 times the rate of use of any substance before age 15, (b) 1.6 times the rate of use of cannabis before age 15, (c) 2.2 times the rate of smoking cigarettes, and (d) 1.9 times the rate of using cannabis multiple times per month (cf. PPVs vs. base rates in Table 3). Thus, screening with the LRS will result in a research sample with significantly elevated rates of early substance use or a subgroup for targeted prevention that is significantly more likely to exhibit early substance use, absent intervention.

Whether screening with the LRS is preferable to universal selection will depend on features of the specific research or clinical application. At



Description: Loeber Risk Score (LRS) at age 9 years old predicting each alcohol/drug use outcome in full sample.



Description: Statistically significant findings in follow-up analyses of differences in the Loeber Risk Score (LRS) AUROC by age in years at which measured.

Fig. 1. AUROC of Loeber Risk Score (LRS) Note. AUROC = area under the receiver operating characteristic curve. AUROC equal to 0.50 indicates prediction at the level of chance. Samples differ between Panel A and Panel B as only participants who completed both age 5 and age 9 assessments were included in the comparisons of AUROC for the LRS measured at age 5 vs. age 9.

Table 3
Performance of Loeber Risk Score (LRS).

Outcome	Base Rate	Screening Threshold	Proportion Selected	PPV	NPV	Accuracy	Sensitivity	Specificity
Used any substance before age 15	0.23	≥1	0.54	0.27	0.82	0.52	0.63	0.49
		≥2	**0.24**	**0.33**	**0.80**	**0.69**	**0.35**	**0.79**
		≥3	0.10	0.40	0.79	0.75	0.18	0.92
		≥4	0.04	0.47	0.78	0.77	0.09	0.97
		≥5	0.02	0.61	0.77	0.77	0.04	0.99
Drank alcohol before age 15	0.15	≥1	0.53	0.16	0.86	0.48	0.56	0.47
		≥2	**0.24**	**0.17**	**0.86**	**0.69**	**0.27**	**0.77**
		≥3	0.10	0.20	0.86	0.79	0.14	0.90
		≥4	0.04	0.20	0.85	0.82	0.06	0.96
		≥5	0.02	0.34	0.85	0.85	0.04	0.99
Used cannabis before age 15	0.15	≥1	0.53	0.19	0.90	0.52	0.68	0.49
		≥2	**0.24**	**0.24**	**0.88**	**0.73**	**0.40**	**0.78**
		≥3	0.10	0.28	0.87	0.81	0.20	0.91
		≥4	0.04	0.30	0.86	0.84	0.09	0.96
		≥5	0.02	0.42	0.86	0.85	0.05	0.99
Smoked cigarettes before age 15	0.05	≥1	0.53	0.08	0.97	0.49	0.77	0.48
		≥2	**0.24**	**0.11**	**0.97**	**0.76**	**0.52**	**0.77**
		≥3	0.11	0.14	0.96	0.87	0.28	0.90
		≥4	0.04	0.22	0.95	0.92	0.18	0.96
		≥5	0.02	0.42	0.95	0.94	0.13	0.99
Drank alcohol monthly during past year at ages 14–16	0.09	≥1	0.54	0.09	0.92	0.48	0.56	0.47
		≥2	**0.24**	**0.13**	**0.92**	**0.73**	**0.34**	**0.77**
		≥3	0.11	0.16	0.92	0.84	0.19	0.90
		≥4	0.04	0.13	0.91	0.88	0.06	0.96
		≥5	0.01	0.26	0.91	0.90	0.04	0.99
Binge drank monthly during past year at ages 14–16	0.03	≥1	0.54	0.03	0.97	0.47	0.60	0.47
		≥2	**0.24**	**0.04**	**0.97**	**0.75**	**0.31**	**0.76**
		≥3	0.11	0.03	0.97	0.87	0.11	0.89
		≥4	0.04	0.02	0.97	0.93	0.03	0.96
		≥5	0.01	0.00	0.97	0.96	0.00	0.98
Used cannabis multiple times per month during past year at ages 14–16	0.05	≥1	0.54	0.07	0.97	0.49	0.69	0.47
		≥2	**0.24**	**0.10**	**0.96**	**0.75**	**0.46**	**0.77**
		≥3	0.11	0.09	0.95	0.86	0.19	0.90
		≥4	0.04	0.14	0.95	0.92	0.11	0.96
		≥5	0.01	0.13	0.95	0.94	0.04	0.99

Note. Base rate = proportion of participants endorsing the target outcome, Screening threshold = cutpoint on the LRS score used to select participants in the screening, Proportion Selected = percentage of participants predicted to display early-onset use, PPV = positive predictive value, NPV = negative predictive value. Performance under the screening threshold recommended by Loeber et al. (2018), a score ≥ 2, is in bold. Screening thresholds above ≥ 5 were not considered because they would identify exceedingly small percentages of the sample (<1%). See supplement for all estimates with 95% confidence intervals. See Table 2 for description of how to interpret performance metrics. Base rates may differ from those in Table 1 due to exclusion of participants with missing data.

a length of five items, the LRS is relatively low burden to complete. However, PPVs remain low in absolute magnitude, even with more stringent cutoffs. At LRS ≥ 2, PPVs ranged from 10 to 33% across the statistically significant outcomes, meaning that 67–90% (i.e., the majority) of children flagged in the screening *will not* go on to display the early onset cannabis/cigarette use. Thus, the decision to use the LRS in any clinical application should acknowledge this fact and consider issues related to cost and potential stigma (Dodge, 2020).

To facilitate use of the LRS going forward, the supplement includes a complete database with estimated performance across potential cutoff scores, at age 5 and age 9, for the full sample and subgroups. Choice of a cutoff score depends on the purpose of the LRS in a given application (Wynants et al., 2019), so we make no general recommendation. Loeber et al.'s suggested default cutoff of LRS ≥ 2 identified about ¼ of children, which is a common scope for targeted prevention programs (Conduct Problems Prevention Research Group, 2020; Dishion & Kavanagh, 2003; Powell et al., 2017).

5.2. Strengths and limitations

Strengths of this study include the use of a large, diverse, nationwide sample to enhance generalizability; conducting a rigorous external validation, wherein item selection, scoring, and recommended cutpoint had been pre-determined (Steyerberg & Harrell, 2016); testing for potential differences by sex, race, and ethnicity; and consideration of multiple substances and definitions of early-onset outcomes. There were also limitations. First, the FFCWS cohort was born in 1998–2000 and thus reached adolescence before recent increases in vaping and the number of states with legal cannabis use by adults (Borodovsky et al., 2016). Second, the survey assessed "cigarette" use, potentially excluding vaping or other forms of nicotine use (Boccio & Jackson, 2021), and asked about "smoked marijuana", potentially excluding other cannabis administration methods and preparations (vaping, edibles, concentrates; Meier et al., 2019). Third, FFCWS survey items were not identical across substances, which may have contributed to differences in predictive performance across substances. Fourth, we relied on youth self-report of alcohol and drug use and could not validate these reports with toxicology.

6. Conclusions

The LRS comprises a brief, low-burden screening measure that can identify children at risk of early substance use at 1.4–2.2 times the rate in the general U.S. population and performs similarly across sexes and racial/ethnic groups. Predictive accuracy is modest, and the LRS' relevance for research design and clinical intervention will depend on context and purpose. Developing more accurate screening measures is a priority for future work and may require the incorporation of a broader set of risk factors along the pathway to early establishment of alcohol and drug use.

Table 4
Comparison of Findings to Loeber et al. (2018).

Substance	Outcome		Current Sample	Samples used in Loeber et al. (2018)		
			FFCWS	CEDAR	PYS	PGS
		N:	2,790	202	217	862
		Nature of sample:	Birth cohort weighted to U.S. Census	High-risk sample: ~ 50% children of males with Substance Use Disorder	High-risk sample: ~50% exceeded thresholds for antisocial behavior at screening into study	Community-based sample, with 1.8:1 oversampling for lowest-income neighborhoods
		Birth years:	1998–2000	~1977–1986	~1980–1981	~1990–1994
		Sex:	52% male 48% female	Males only	Males only	Females only
		Location:	20 cities across U.S.	Pittsburgh, PA	Pittsburgh, PA	Pittsburgh, PA
		Mean age at measurement of LRS:	9.4 years	11.4 years	10.2 years	9.6 years
			AUROC [95% CI]	**AUROC (*p*)**	**AUROC (*p*)**	**AUROC (*p*)**
Any alcohol/ drugs (collapsed)	Used before age 15		0.59 [0.55, 0.63]	–	–	–
Alcohol	Used before age 15		0.52 [0.47, 0.58]	–	–	–
	Use disorder before age 15		–	0.67 (*ns*)	–	–
	Monthly use before age 15		–	0.62 ($p < .05$)	–	–
	Monthly use during past year, at ages 14–16		0.54 [0.47, 0.61]	–	–	–
	Monthly binge drinking during past year, at ages 14–16		0.54 [0.44, 0.64]	–	–	–
Cannabis	Used before age 15		0.62 [0.57, 0.67]	–	–	–
	Used multiple times per month during past year, at ages 14–16		0.62 [0.55, 0.69]	–	–	–
	Currently using monthly, at age ~14.7		–	0.76 ($p < .001$)	–	–
	Used $\geq$ 5 times during the past year, at age ~14.5–16.0		–	0.69 ($p < .001$)	0.59 (*ns*)	0.65 ($p < .001$)
Cigarettes	Used before age 15		0.68 [0.60, 0.77]	–	–	–
Illicit drugs excluding cannabis	Used before age 15		–	0.65 ($p < .01$)	–	–
	Use disorder before age 18		–	0.65 ($p < .01$)	–	–

Note. FFCWS = Fragile Families and Child Wellbeing Study, CEDAR = Center for Education and Drug Abuse Research, PYS = Pittsburgh Youth Study, PGS = Pittsburgh Girls Study, LRS = Loeber Risk Score, AUROC = area under the receiver operating characteristic curve, 95% CI = 95% confidence interval. Values for FFCWS are from age 9 assessment. Ages are in years. AUROCs from the CEDAR, PYS, and PGS studies are all based on holdout data not used by Loeber et al. (2018) when selecting items for the measure. Loeber et al. (2018) did not report other metrics of performance (e.g., positive/negative predictive values) for the holdout data only, so they are not included here.

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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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.addbeh.2022.107277.

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