

# Prospective Identification of Adolescent Suicide Ideation Using Classification Tree Analysis: Models for Community-Based Screening

Ryan M. Hill, Benjamin Oosterhoff, and Julie B. Kaplow  
University of Texas Health Science Center at Houston

**Objective:** Although a large number of risk markers for suicide ideation have been identified, little guidance has been provided to prospectively identify adolescents at risk for suicide ideation within community settings. The current study addressed this gap in the literature by utilizing classification tree analysis (CTA) to provide a decision-making model for screening adolescents at risk for suicide ideation. **Method:** Participants were  $N = 4,799$  youth ( $M_{\text{age}} = 16.15$  years,  $SD = 1.63$ ) who completed both Waves 1 and 2 of the National Longitudinal Study of Adolescent to Adult Health. CTA was used to generate a series of decision rules for identifying adolescents at risk for reporting suicide ideation at Wave 2. **Results:** Findings revealed 3 distinct solutions with varying sensitivity and specificity for identifying adolescents who reported suicide ideation. Sensitivity of the classification trees ranged from 44.6% to 77.6%. The tree with greatest specificity and lowest sensitivity was based on a history of suicide ideation. The tree with moderate sensitivity and high specificity was based on depressive symptoms, suicide attempts or suicide among family and friends, and social support. The most sensitive but least specific tree utilized these factors and gender, ethnicity, hours of sleep, school-related factors, and future orientation. **Conclusions:** These classification trees offer community organizations options for instituting large-scale screenings for suicide ideation risk depending on the available resources and modality of services to be provided. This study provides a theoretically and empirically driven model for prospectively identifying adolescents at risk for suicide ideation and has implications for preventive interventions among at-risk youth.

## *What is the public health significance of this article?*

This study provides a data-driven model for prospectively identifying adolescents at risk for suicide ideation. If replicated in future studies, this model could be used by organizations to provide options for instituting large-scale screenings for suicide ideation risk depending on the available resources and modality of services available.

**Keywords:** adolescent, suicide ideation, screening, prevention, classification tree analysis

Adolescent suicide-related behaviors are a substantial health problem in the United States. Suicide is the second leading cause of death for individuals between the ages of 15 and 24 years

(Centers for Disease Control and Prevention, 2016). Suicide ideation is also frequent during adolescence: Data from the Youth Risk Behavior Surveillance System, a survey of more than 15,000 U.S. high school students, have indicated that 17.7% of high school students seriously considered suicide in the previous 12 months (Kann et al., 2016a, 2016b). Because suicide ideation is a robust predictor of future suicidal behavior (Posner et al., 2011) and is indicative of psychological distress (Troister & Holden, 2010), public health officials have longstanding interest in the identification, prevention, and treatment of suicide ideation among youth. A large number of risk markers for suicide ideation have been identified (e.g., Evans, Hawton, & Rodham, 2004; Gould, Greenberg, Velting, & Shaffer, 2003; Stewart et al., 2005), yet little guidance has been provided to assist in the prospective identification of adolescents at risk for suicide ideation. The current study addresses this gap in the literature by utilizing a large, longitudinal data set and classification tree analysis to provide a means for prospectively identifying adolescents at risk for suicide ideation.

The National Strategy for Suicide Prevention has identified screening for suicide risk as crucial for assisting health care

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Ryan M. Hill, Benjamin Oosterhoff, and Julie B. Kaplow, Department of Psychiatry and Behavioral Sciences, University of Texas Health Science Center at Houston.

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Correspondence concerning this article should be addressed to Ryan M. Hill, 1941 East Road, Suite 2316, Houston, TX 77054. E-mail: [ryan.m.hill@uth.tmc.edu](mailto:ryan.m.hill@uth.tmc.edu)

providers in directing resources to at-risk individuals (U.S. Department of Health and Human Services, Office of the Surgeon General, and National Action Alliance for Suicide Prevention, 2012). Recent efforts to move suicide prevention “upstream” have placed greater emphasis on early prevention, prior to the development of acute suicide risk. Data from the Youth Risk Behavior Surveillance Survey have indicated that among adolescents, 8.6% reported making a suicide attempt in the previous 12 months (Kann et al., 2016a, 2016b). Those data also indicated that 89.1% of adolescent suicide attempters reported suicide ideation in the previous 12 months. Thus, a substantial percentage of suicidal attempters also experience suicide ideation (data available from the Centers for Disease Control and Prevention; [www.cdc.gov](http://www.cdc.gov)). Critically, individuals reporting suicide ideation also reported elevated levels of psychological pain and distress (Troister & Holden, 2010), including psychache (Olié, Guillaume, Jaussent, Courtet, & Jollant, 2010) and depressive symptoms (Evans et al., 2004), indicating that suicide ideation itself should be addressed as a source of mental health burden, regardless of whether adolescents progress to engaging in suicidal behaviors. That is, if suicide ideation is a response to overwhelming psychological pain (see Schneidman, 1993), then suicide ideation should be the target of screening, prevention, and intervention efforts—and its association with future suicide-related behaviors (Posner et al., 2011) only highlights the need to intervene early and prevent suicide ideation.

To date, various theories of suicide ideation have been proposed. Schneidman’s (1993) theory of suicide as psychache suggests that any source or indicator of psychological pain is a risk marker for suicide. Studies have identified, consistent with this theory, a number of mental health factors associated with suicide ideation, including depressive symptoms, mood disorders, anxiety disorders, and anhedonia (Evans et al., 2004; Winer, Nadorff, Ellis, & Salem, 2014). Baumeister’s (1990) escape theory would indicate that sources of stress and/or lack of problem-solving resources would place an individual at risk for cognitive deconstruction and thoughts of suicide. Prior research has indicated that, consistent with this theory, exposure to violence, sleep problems, and family and peer relationship problems are associated with suicide ideation (Evans et al., 2004; Feigelman & Gorman, 2008; Kerr, Preuss, & King, 2006; Winer, Nadorff, Ellis, & Salem, 2014; Wong, Brower, & Zucker, 2011). Finally, the interpersonal-psychological theory of suicide (Joiner, 2005; Van Orden et al., 2010) identifies perceived burdensomeness and thwarted belongingness as risk markers for suicide ideation. Perceived burdensomeness and thwarted belongingness have demonstrated significant associations with suicide ideation in several studies (for reviews see Hill & Pettit, 2014; Stewart, Eaddy, Horton, Hughes, & Kennard, 2015). Emerging evidence has also pointed to perceived burdensomeness and thwarted belongingness as proximal risk factors for suicide ideation through which other risk markers may operate (e.g., Buitron et al., 2016; Hill & Pettit, 2013). Consistent with this theory, factors such as religiosity, social support, school attendance, and school connectedness (all of which may contribute to a sense of belongingness) have been associated with suicide ideation (Evans et al., 2004; Rasic et al., 2009).

Although the theoretical and empirical literature has identified a wide-ranging list of predictors of suicide ideation, these predictors have not been utilized to prospectively distinguish adolescent suicide ideators from their nonsuicidal peers. To date, risk screen-

ing has focused on the identification of concurrent suicide ideation (Hallfors et al., 2006; Horowitz et al., 2001; King, O’Mara, Hayward, & Cunningham, 2009; Shaffer et al., 2004) or prospective risk for suicide attempts (Larzelere, Smith, Batenhorst, & Kelly, 1996; Wichstrøm, 2000). Currently developed screening approaches such as the TeenScreen program (Shaffer et al., 2004) focus on identifying adolescents who are currently at risk, due to current suicide ideation or other identified risk markers (e.g., depression and substance use). The Risk of Suicide Questionnaire (Horowitz et al., 2001) uses a similar approach to assess concurrent risk. Similarly, King and colleagues (2009) developed a screen for identifying at-risk adolescents in an emergency department setting, but it, too, was designed for detecting concurrent risk. *Concurrent* screening emphasizes reducing distress in order to prevent suicidal behaviors. Less attention has been paid to *prospective* screening—identifying adolescents who are likely to report suicide ideation in the future. Prediction of suicide ideation beyond the proximal period is necessary for administering preventive interventions. Consistent with conceptualizing suicide ideation as a state of distress, prospective screening provides an opportunity to intervene and prevent distress; it also provides an additional layer of upstream screening and prevention in the overall network of suicide-prevention initiatives.

The present study begins to address this issue and provides an empirical basis for decision-making and referral via a classification tree approach to predict suicide ideation using data from a large sample of adolescents. Classification tree analysis (CTA) is an exploratory, data-driven paradigm that provides a framework for predicting a categorical outcome (e.g., suicide ideation or no suicide ideation) based on a group of theoretically derived independent variables. This approach has been applied to suicide attempts to distinguish recent suicide attempters, past suicide attempters, and nonattempters (Mann et al., 2008) and to predict repeated self-harm among emergency department patients (Steege et al., 2012). To our knowledge, this approach has not yet been used to prospectively predict the presence of adolescent suicide ideation. Using CTA to prospectively identify adolescents at risk for suicide ideation may be particularly useful for screening at-risk adolescents in community settings. Many community settings, such as schools and youth organizations, have frequent contact with adolescents with a wide range of mental health needs but often lack the training to provide services to screen for suicide risk. Providing community organizations with decision trees help lay persons to better screen for suicide risk upstream, before suicide ideation manifests, and refer adolescents to preventive interventions.

A series of variables selected to represent theoretically and empirically derived risk markers were drawn from the National Longitudinal Study of Adolescent to Adult Health (Add Health; Harris & Udry, 2008) database. Drawing from three primary theories, including Schneidman’s (1993) theory of suicide, Baumeister’s (1990) escape theory, and the interpersonal-psychological theory of suicide (Joiner, 2005; Van Orden et al., 2010), we selected variables based on their theoretical relevance and strong empirical support regarding their respective relations to suicide ideation. These variables included indicators of psychological functioning (e.g., depressive symptoms, behavioral activation, and sleep as potential indicators of overall psychological pain; Schneidman, 1993), escape or avoidance

behavior (e.g., skipping school; Baumeister, 1990), school-related variables as indicators of school support (an element of belongingness; Joiner, 2005), demographic factors, and indicators of previous suicide ideation or exposure to suicide-related behaviors in others (see Feigelman & Gorman, 2008). Given the robust relation between suicide ideation and future suicide attempts (Posner et al., 2011) and the psychological distress associated with suicide ideation (Troister & Holden, 2010), accurately predicting youth at risk for suicide ideation may serve both to enhance suicide prevention efforts and to reduce the mental health burden associated with suicide ideation.

## Method

### Participants and Procedures

The current sample was drawn from the Add Health database. The data were obtained through the Inter-University Consortium for Political and Social Science Research (ICPSR; Harris & Udry, 2008). Add Health participants provided written informed consent for participation in all aspects of Add Health, and the study was approved by the appropriate institutional review board. In 1994–1995, Add Health representatives surveyed youth attending a nationally stratified sample of 132 high schools and middle schools (Grades 7–12). As part of the overall study, a subset of participants from these high schools completed at-home interviews. In Wave 1 (1994–1995), 20,745 adolescents ( $M_{\text{age}} = 15.0$  years, range = 11–21) completed the first assessment involving in-home interviews using computer-assisted interview methods. A sample of  $N = 14,738$  participants were then reinterviewed 1 year after the initial assessment (Wave 2). For this follow-up assessment, adolescent in-home interviews were completed using audio-computer-assisted self-interview technology on laptop computers for sensitive health-risk behavior questions. This study utilizes the public use data set, which contains a random subsample drawn from the larger Add Health database. The public use data included responses for  $n = 6,054$  youth at Wave 1 and  $n = 4,834$  youth reassessed at Wave 2. Full details of the Add Health procedures and study design have been published previously (e.g., Harris, 2011).

Consistent with guidelines for Add Health data users (Chantala, 2006), we limited our analyses to  $n = 4,799$  youth ( $M_{\text{age}} = 16.15$ ,  $SD = 1.63$ , at Wave 1) who completed both waves of at-home interviews and the measure of suicide ideation at Wave 2. Participants (52.3% female) were primarily White (63.7%), African American or Black (23.7%), Asian (3.7%), Native American (3.1%), and other (6.1%). The median household income was \$40,000 (range = \$0–\$900,000). Regarding parents' education, 14.9% of parent respondents (15.8% of spouses) did not complete high school, 40.9% completed high school but did not have any college training (38.0% of spouses), 19.2% completed some college (15.9% of spouses), and 25.1% obtained a college degree or higher (29.7% of spouses). Additional demographic data from the Add Health public use data sets have also been published previously (Harris & Udry, 2008).

### Measures

Risk markers were chosen based on empirical and theoretical support to indicate that they are risk markers for suicide ideation

(e.g., Evans et al., 2004; Feigelman & Gorman, 2008; Kerr et al., 2006; Stewart et al., 2005; Wong et al., 2011).

**Psychosocial factors (Wave 1).** Several psychosocial factors—including depressive symptoms, social support, violence exposure, and behavioral engagement—as well as average number of hours of sleep, religiosity, and future orientation, which are described in more detail next, were selected from questions asked during the Wave 1 in-home interview. Three single items included assessed number of hours of sleep (answered in whole-number increments), the importance of religion (on a 4-point scale ranging from 1 = *very important* to 4 = *not important at all*), and self-reported likelihood of living until age 35 (rated on a 9-point scale ranging from 0 = *no chance* to 8 = *it will happen*), respectively. Exact wording and answer choices for all items are provided in Table 1.

A depressive symptom score was generated by calculating the sum of 19 items ( $\alpha = .86$ ) paralleling those on the Center for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977). Items were rated on a 4-point Likert scale ranging from 0 (*rarely or none of the time*) to 3 (*most or all of the time*), with total scores ranging from 0 to 57.

A social support score was generated by calculating the sum of eight items ( $\alpha = .79$ ) that assessed how much the adolescents felt cared for by adults, teachers, parents, and friends, as well how much adolescents have fun with their families, how much their families understand and pay attention to them, and how much they desire to leave home (reverse-coded). Each item was rated from 1 (*not at all*) to 5 (*very much*), with total scores ranging from 8 to 40.

A violence exposure score was generated by calculating the sum of six items ( $\alpha = .70$ ) concerning seeing someone shot or stabbed, being cut or stabbed, being shot or stabbed, having a knife or gun pulled on you, pulling a knife or gun on someone else, and being jumped. Each item was coded as 0 = *never*, 1 = *once*, and 2 = *more than once* in the previous 12 months, with total scores ranging from 0 to 12.

A behavioral engagement score was generated by calculating the sum of eight items assessing engagement in pleasurable activities in the previous week, such as work around the house, hobbies, watching TV, exercise, team sports, cycling or skateboarding, and hanging out with friends. Each item was rated on a 4-point scale ranging from 0 (*not at all*) to 3 (*5 or more times*), with total scores ranging from 0 to 24. Internal consistency is not reported because items were not expected to be intercorrelated.

**School-related factors (Wave 1).** Several school-related factors were selected from questions asked during the Wave 1 in-home interview. Items included school attendance (coded as 0 = *no* and 1 = *yes*), absences (rated on a 4-point scale ranging from 0 = *never* to 4 = *more than 10 days*), feeling safe in school (rated on a 5-point scale ranging from 0 = *strongly agree* to 4 = *strongly disagree*), and learning about suicide as part of a class in school (coded 0 = *no* and 1 = *yes*). Each item included in the classification tree analysis was based on a single item. Items selected for inclusion in the analysis, including their exact wording and answer choices, are provided in Table 1.

**Suicide-related behaviors (Wave 1).** Single-item indicators were used to assess adolescent reported suicide ideation, suicide attempts, suicide attempts requiring medical intervention, and suicide attempts or suicide by family and friends. Exact wording for

Table 1  
 Percentages and Means/Standard Deviations of Demographic and Clinical Characteristics of Suicide- and Nonsuicide-Ideator Groups

Variable or factor	Suicide ideators (n = 523)		Nonsuicide ideators (n = 4,276)	
	%	M (SD)	%	M (SD)
<b>Demographics</b>				
Gender (female)	66.2		50.6	
Ethnicity (Hispanic)	10.5		11.8	
Race (White/African American)	72.5/19.3		67.0/24.3	
Age (in years)		16.11 (1.55)		16.15 (1.64)
<b>School-related factors</b>				
Are you presently in school? ( <i>yes/no</i> )	97.7		98.4	
Have you learned about the following in a class at school: suicide? ( <i>yes/no</i> )	63.3		66.9	
During this school year, how many times have you been absent from school for a full day with an excuse—for example, because you were sick or out of town? ( <i>never, 1–2 days, 3–10 days, more than 10 days</i> )		1.80 (.84)		1.59 (.86)
How many times have you skipped school for a full day without an excuse? (number)		2.56 (9.54)		1.57 (6.66)
How much do you agree or disagree with the following statements: You feel safe in your school. (5-point Likert scale, <i>strongly agree</i> to <i>strongly disagree</i> )		2.40 (1.08)		2.17 (1.03)
<b>Suicide-related behaviors (all items assessed with <i>yes/no</i> response options)</b>				
During the past 12 months, did you ever seriously think about committing suicide?	44.6		8.9	
During the past 12 months, how many times did you actually attempt suicide?	16.6		2.1	
Did any [suicide] attempt result in an injury, poisoning, or overdose that had to be treated by a doctor or nurse?	4.0		.7	
Have any of your friends tried to kill themselves during the past 12 months?	35.6		16.4	
Have any of your friends succeeded in committing suicide in the past 12 months?	6.5		2.4	
Have any of your family members tried to kill themselves during the past 12 months?	10.9		4.1	
Have any of your family members succeeded in committing suicide in the past 12 months?	2.1		1.0	
<b>Psychosocial factors</b>				
Depressive symptoms		16.38 (8.37)		11.87 (6.31)
Social support		29.82 (5.28)		32.53 (4.60)
Violence exposure		1.09 (1.79)		.93 (1.62)
Behavioral engagement		11.52 (3.26)		11.69 (3.34)
How many hours of sleep do you usually get? (number)		7.67 (1.54)		7.91 (1.40)
On a scale from “No chance” to “It will happen” what do you think are the chances you will: live to age 35? (9-point scale)		4.20 (.92)		4.40 (.85)
How important is religion to you? ( <i>very important, fairly important, fairly unimportant, and not important at all</i> )		1.75 (.79)		1.62 (.76)

Note. Percentages indicate the percentage who responded “yes” except where noted.

these items are provided in Table 1. Binary responses for each question were recoded with 0 = *no* and 1 = *yes*.

**Suicide ideation (Wave 2).** Suicide ideation at the Wave 2 in-home interview was the dependent variable. The item “During the past 12 months, did you ever seriously think about committing suicide?” was coded with 0 = *no* and 1 = *yes*.

## Data Analysis

Classification tree analysis (CTA) was used to generate a series of decision rules for identifying adolescents at risk for reporting suicide ideation at Wave 2. CTA is an exploratory, data-driven technique based on recursive partitioning of data in an effort to maximize the predictive accuracy of a given categorical outcome. CTA attempts to optimize categorization of subjects into outcome groups by partitioning the sample via a sequential decision proce-

dure. CTA identifies the optimal cutoff point(s) for each independent variable using binary splits to maximize the accuracy of that predictor for classifying cases on the dependent variable. CTA then tests whether the optimal cutoff point provides an improvement in prediction of the outcome, defined as minimization of model misclassification cost. Of all available independent variables, the one that provides an optimal cutoff point that results in the greatest decrease in model misclassification cost is selected and a branch created. This cutoff point then becomes a “node,” and the procedure is repeated recursively until there are no additional improvements in model misclassification cost possible, based on the independent variables provided, or until a minimum node size is reached as a stopping point.

CTA utilizes minimization of model misclassification cost as the criterion for improvement in model fit. Misclassification cost refers to the relative penalty for mistakenly classifying an individ-

ual as a member of any group other than the one to which the person belongs. Misclassification cost is user-specified with a default setting that awards an equal penalty for any misclassification of a participant. Misclassification cost can be modified to include greater penalties for specific misclassifications in an effort to increase sensitivity at the potential expense of specificity. Whereas sensitivity refers to the proportion of true positives (actual suicide ideators) correctly identified by the classification tree, specificity refers to the proportion of true negatives correctly identified by the classification tree (Altman & Bland, 1994). To identify the classification trees with optimal sensitivity and specificity, we utilized a variety of potential misclassification ratios ranging from 1:1 (i.e., equal "cost" or penalty for misclassification for false negatives compared with false positives) to 15:1 (i.e., a 15 times greater penalty for false negatives compared with false positives).

CTA was run using CRUISE Version 3.6.4 software (Kim & Loh, 2008). All predictors, measured at Time 1, were entered as independent variables, and suicide ideation at Time 2 was used as the dependent variable. The utility of each classification tree was determined based on the ratio of true positives to false positives, the percentage of the sample identified as at risk, and the potential for use in community settings. For each classification tree, a univariate split was determined using a 2D variable selection method via exhaustive search with prior probabilities estimated from the data. A 10-fold cross-validation procedure was implemented to prune the resulting trees using a .5 SE limitation and requiring a minimum node size of 24 cases for further splits to produce a final classification tree with high replicability (Kim & Loh, 2003). An imputation algorithm was used to temporarily impute values for the cases with missing data (1% of cases) on the split variable. Those cases were then split according to the decision rule and the imputed values removed (Kim & Loh, 2001).

## Results

### Demographics, Descriptive Statistics, and Correlations

Demographic and clinical characteristics of both the suicide ideator and nonsuicidal ideator groups are provided in Table 1. Overall, 10.9% of adolescents reported suicide ideation at Wave 2 (the suicide ideator group).

### Classification Tree Analysis

**CTA estimation and selection.** A series of CTAs were estimated based on misclassification cost ratios ranging from 1:1 to 15:1. Descriptive information is provided for each tree in Table 2, including overall classification accuracy, the number of nodes in the classification tree, the number of suicide ideators correctly identified and missed, and the number of false positives. The sensitivity and specificity of each solution was inspected via receiver operating characteristic curve (see Figure 1). Tree 1 had poor sensitivity, and Trees 8 and 9 had poor specificity (high false positive rates), limiting their utility for screening. Tree 2 appears to have provided a unique solution with moderate sensitivity and high specificity. Trees 3 and 4 provided nearly identical estimates of sensitivity and specificity, with Tree 4 providing slightly better sensitivity than did Tree 3 with minimal cost to specificity. Similarly, Trees 5, 6, and 7 provided similar estimates of sensitivity and specificity, although Tree 5 demonstrated slightly better sensitivity relative to Trees 6 and 7. Thus, Trees 2, 4, and 5 provided distinct solutions while maximizing improvement over chance classification.

**Tree 2: Low sensitivity, high specificity.** Tree 2 represents classification trees using a 2:1 to 6:1 misclassification cost ratio, because these produced identical trees, depicted in Figure 2. Tree 2 identified 233 of 523 suicide ideators (or 44.6% of suicide ideators) and an additional 380 false positives. For Tree 2, the ratio of true positives to false positives was 1:1.6. That is, for every correctly identified suicide ideator, 1.6 adolescents were incorrectly classified as suicide ideators. Tree 2 can be interpreted as follows: The initial sample contained 4,799 individuals, of whom 10.9% reported suicide ideation at Wave 2. The only split was a history of suicide ideation at Wave 1. Of the 4,186 adolescents without a history of suicide ideation, 290 were suicide ideators, for an incidence rate of 6.9%. Of the 613 adolescents with a history of suicide ideation, 233 reported suicide ideation at Wave 2, for an incidence rate of 38.0%. Overall, Tree 2 identified 12.8% of the sample as at risk. Tree 2 produced a solution with high accuracy among identified youth and was based on a single predictor. However, this solution failed to identify a large number of youth at risk for suicide ideation.

**Tree 4: Moderate sensitivity, high specificity.** Tree 4 represents classification trees using 8:1 to 9:1 misclassification cost

Table 2  
Descriptive Information and Classification Accuracy for Each Classification Tree

Tree	Cost ratio	Terminal nodes	% correct	True positives	True negatives	False positives	False negatives	True positive: false positive ratio	Sensitivity (%)	Specificity (%)
1	1:1	3	89.5	45	4,250	26	478	1:.58	8.6	99.4
2	<b>2:1–6:1</b>	<b>2</b>	<b>86.0</b>	<b>233</b>	<b>3,896</b>	<b>380</b>	<b>290</b>	<b>1:1.63</b>	<b>44.6</b>	<b>91.1</b>
3	7:1	5	80.1	309	3,537	739	214	1:2.39	59.1	82.7
4	<b>8:1–9:1</b>	<b>8</b>	<b>80.1</b>	<b>327</b>	<b>3,518</b>	<b>758</b>	<b>196</b>	<b>1:2.32</b>	<b>62.5</b>	<b>82.3</b>
5	<b>10:1</b>	<b>15</b>	<b>69.3</b>	<b>406</b>	<b>2,918</b>	<b>1,358</b>	<b>117</b>	<b>1:3.44</b>	<b>77.6</b>	<b>68.2</b>
6	11:1	10	68.6	395	2,897	1,379	128	1:3.49	75.5	67.8
7	12:1	9	67.8	395	2,860	1,416	128	1:3.58	75.5	66.9
8	13:1–14:1	3	40.1	467	1,458	2,818	56	1:6.03	89.3	34.1
9	15:1	4	37.6	485	1,321	2,995	38	1:6.18	92.7	30.9

Note. Bold font indicates suggested optimal solutions.

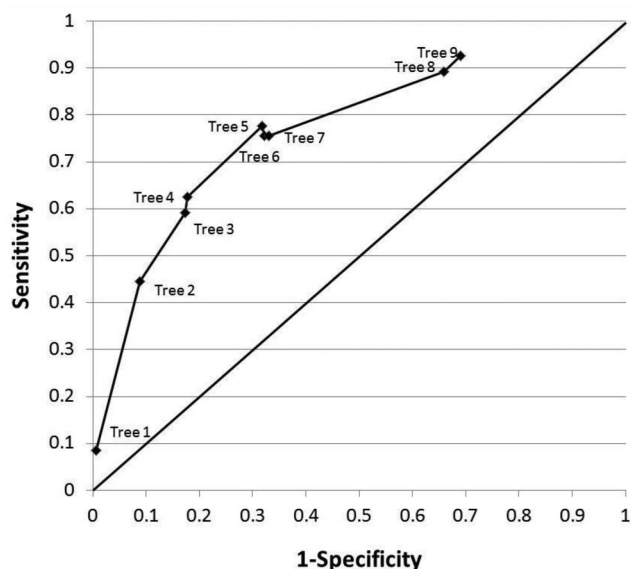


Figure 1. Receiver operating characteristic curve indicating sensitivity and specificity of each classification tree.

ratios and builds on the solution presented in Tree 2 (see Figure 2). This increase in the misclassification ratio resulted in correctly identifying a larger number of suicide ideators but also misclassifying a larger number of youth who did not endorse suicide ideation. Specifically, Tree 4 correctly identified 327 suicide ideators (or 62.5% of suicide ideators) and an additional 758 false positives. For Tree 3, the ratio of true positives to false positives was 1:2.3. That is, for every correctly identified suicide ideator, 2.3 adolescents were incorrectly classified as suicide ideators. Among those who did not report suicide ideation at Wave 1, depressive symptom score was the next node that contributed to the most accurate classification of Wave 2 suicide ideators. For youth with lower depressive symptom scores ( $\leq 8.5$ ), having a friend attempt suicide, having a friend die by suicide, and having a family member die by suicide characterized the next successive series of nodes (respectively) that provided the best prediction of suicide ideators at Wave 2. For youth with greater depressive symptom scores at Wave 1 ( $\geq 8.5$ ), family suicide attempt characterized the next node, and for youth who did not have a family member attempt suicide, social support characterized the next node and provided the best improvement in accuracy. Tree 4 identified 22.6% of the sample as at risk. In sum, Tree 4 produced a solution that identified a greater percentage of suicide ideators than did Tree 2 but also a greater number of false positives.

**Tree 5: High sensitivity, moderate specificity.** Tree 5 represents the classification trees using a 10:1 misclassification cost ratio and built upon Tree 4 (see Figure 2).<sup>1</sup> Tree 5 identified 406 suicide ideators (or 77.6% of suicide ideators) and an additional 1,358 false positives. For Tree 5, the ratio of true positives to false positives was 1:3.3. For every correctly identified suicide ideator, 3.3 adolescents were incorrectly classified as suicide ideators. For youth with less social support, Hispanic ethnicity was the next node. For youth with greater social support, learning about suicide in school characterized the next node. For youth who did not learn about suicide in school, average number of hours of sleep and

school absences characterized the next series of nodes (respectively), which provided the best prediction of suicide ideation at Wave 2. For youth who did learn about suicide in school, sex and future orientation characterized the next series of nodes (respectively) and provided the best improvement in accuracy. Overall, Tree 5 identified 36.8% of the sample as at risk. Tree 5 produced a solution with high sensitivity, which correctly identified an additional 15% of suicide ideators, but also generated a substantially greater number of false positives compared with Tree 4.

## Discussion

The present study provided a data-driven model for decision-making to assist in prospectively identifying adolescents at risk for suicide ideation. Suicide-ideation risk markers were identified based on previous research and theory, and a classification tree approach was used to identify adolescents who reported suicide ideation 1 year after a baseline assessment. Classification Trees 2, 4, and 5 provided distinct solutions that maximized improvement over chance classification. Selection of the optimal classification tree will depend on the resources available for providing preventive interventions to adolescents identified as at risk for suicide ideation. The available resources (e.g., funding for the cost of preventive interventions, clinician time and availability, space for service provision) will dictate the balance between sensitivity and specificity for a particular organization. If resources allow, the most sensitive tree should typically be used in order to reach the greatest number of at-risk youth. Thus, Tree 5 appears to offer the best solution, with high sensitivity and moderate specificity, and may prove useful for implementing low-cost, easily disseminated preventive interventions. Due to the high percentage of adolescents who screen as at risk for suicide ideation using Tree 5, resource-intensive interventions such as individual or small group interventions may not be feasible as follow-up to screening. Trees 2 and 4 offer higher specificity. Because Trees 2 and 4 identify a smaller percentage of adolescents as at risk, it may be possible to direct these adolescents to more resource-intensive interventions.

## Clinical Utility

The utility of each classification tree depends on its sensitivity, specificity, and the goals of the organization. The inverse relation between sensitivity and specificity allows for modification of selection criteria based on resource availability and the services to be offered. Overall, Tree 5 offers the most useful model to organizations that are primarily focused on identifying the greatest number of at-risk adolescents (high sensitivity). Trees 2 and 4 provide useful alternatives if an organization wishes to place a greater emphasis on specificity.

Tree 5 was the most sensitive, identifying over 75% of suicide ideators, at the cost of a large number of false positives. For an organization screening 500 adolescents, Tree 5 would identify approximately 184 adolescents as being at risk for suicide ideation. With a high number of adolescents identified as at risk, a resource-intensive preventive intervention such as individual therapy may

<sup>1</sup> Diagrams for additional classification trees are not provided due to their comparatively poor performance and to space constraints. Tree diagrams for these trees are available from the first author upon request.

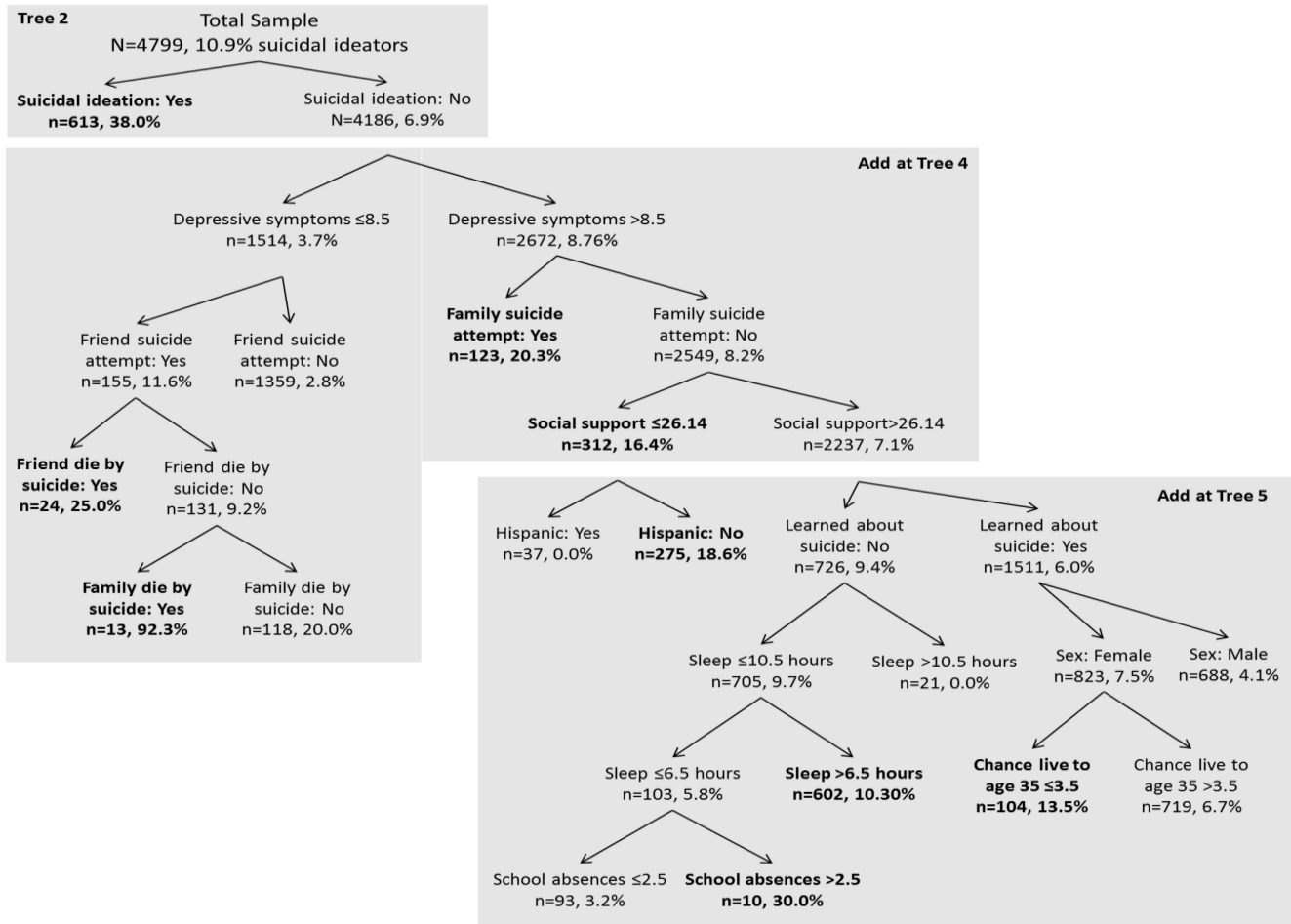


Figure 2. Classification trees for identifying suicidal ideators at Wave 2. Percentages are incidence rates for each node. Terminal nodes in bold indicate a prediction of suicide ideation at Wave 2.

not be feasible for organizations screening more than a modest number of adolescents. Tree 5 would be most appropriate when utilizing a low-cost, easily implemented preventive intervention (e.g., a web-based preventive intervention; see Hill & Pettit, 2016). When the cost of services per adolescent is low, the greater sensitivity of Tree 5 may outweigh its moderate specificity.

Tree 4 had moderate sensitivity, identifying more than 60% of suicide ideators, with fewer false positives. For screening 500 adolescents, Tree 4 would identify approximately 113 adolescents as at risk. Tree 4 may identify too many adolescents to effectively provide one-to-one preventive interventions unless substantial resources are available for service delivery. Tree 4 may be better suited when an organization plans to deliver lower cost interventions, such as group-based programs. For example, an organization might screen adolescents and refer them to a group-based prevention program, such as the Adolescents Coping with Stress course (Clarke et al., 1995).

Tree 2 demonstrated low-to-moderate sensitivity, identifying nearly half of suicide ideators, with relatively few false positives. If an organization such as a community group or school wished to provide a one-to-one preventive intervention to its members or students, Tree 2 would restrict the target population to approxi-

mately one in eight adolescents, or approximately 64 out of every 500 adolescents screened, allowing a small team of providers to reach the entire identified target population while using a brief, individual intervention. In an environment with limited resources for implementing preventive interventions, or when the cost of implementing preventive interventions to a large population would be prohibitive (e.g., when funding for a clinician's time and effort is limited), Tree 2 may provide an efficient delivery of available resources with a high percentage of services delivered to the target population.

### Integrating Prospective Screening Into a Suicide Prevention Framework

The classification trees developed here are intended to fit within a larger suicide-prevention framework that includes universal prevention approaches, screening for inclusion in selected or indicated preventive interventions, and screening and intervention for various levels of suicide-related behaviors (i.e., services for suicide ideators, suicide attempters, and acutely suicidal adolescents). Given the prospective nature of the classification trees developed here, adolescents who screen as at risk may not be experiencing

suicidal thoughts or other psychiatric disorders at the time of the screening. Thus, the classification trees can be used to identify potential recipients of selective preventive interventions, rather than as a referral for further evaluation. These classification trees are not meant as a substitute for concurrent screening and in-depth assessment of suicide risk by a trained mental health clinician. Rather, they are meant to enhance the existing array of screening and assessment mechanisms already developed, by identifying a subset of adolescents for whom selective preventive interventions might be particularly well suited. Organizations desiring to enhance their prevention efforts and prevent suicide ideation might screen adolescents for suicide ideation risk and direct positive screens to preventive interventions.

One benefit of utilizing a classification tree for identifying adolescents in need of preventive interventions is that it does not require full information on each risk marker in the tree. Rather, the assessment is adaptive such that only the information required to determine a split on the classification tree is needed. For example, to utilize Tree 5, a screen would first ask “During the past 12 months, did you ever seriously think about committing suicide?” If the adolescent responds affirmatively, classification is complete and no additional information is necessary. If the adolescent responds negatively, then an assessment of depressive symptoms follows. Although Tree 5 contains 14 branches, classification of a single adolescent requires, at most, seven pieces of information, with the vast majority of adolescents requiring fewer pieces of information for classification.

Electronic screening methods would allow for efficient screening using a classification tree approach, because these methods could adaptively select the salient information in real time, minimizing time required for screening. Simple decision logic via online platforms or smartphone applications could be used to create a screening measure that adapts to adolescents’ responses in real time. With each question determined by the previous split on the classification tree, the entire process may require only a few minutes, without necessitating extensive effort by office personnel. This process also results in an adaptive and personalized screening that minimizes adolescents’ time investment. Similarly, schools and organizations could provide a link to the screening for adolescents during events or club meetings or even when distributing electronic report cards. Organizations would direct students to an appropriate follow-up, such as individual- or group-based prevention provided by a school counselor. Thus, future research should consider the application of this screening via electronic platforms. These classification trees also highlight the need for brief prevention programs that require minimal resources for dissemination. Further development of web-based programs (e.g., the LEAP intervention; Hill & Pettit, 2016), smartphone applications (e.g., the HopeBox application; Bush et al., 2017), or single-session interventions (e.g., Teen Options for Change; King, Gipson, Horwitz, & Opperman, 2015) would allow organizations with limited resources to prove appropriate follow-up care.

As with any screening approach, however, organizations must weigh the costs and benefits of screening for suicide-ideation risk. Each screen includes a number of false negatives (missed cases) and false positives. False negatives result in missed opportunities to provide preventive interventions. For this reason, organizations may wish to select the most sensitive classification tree their resources allow. Because false negatives occurred in every screen-

ing, it is important that this screen be utilized as part of a larger suicide prevention system, with risk screening occurring in a variety of settings to identify as many at-risk adolescents as possible. False positives (adolescents who are not at risk but are identified as in need of services), although potentially less concerning than are false negatives, carry a cost as well. Providing services to false positives may reduce already limited prevention resources. Further, when providing preventive interventions, care must be taken to promote a positive view of the mental health care system and avoid subjecting adolescents to stigma from peers or adults. Any preventive interventions utilized as a response to this screening should have demonstrated efficacy and safety prior to their use.

### Interpretation of Tree Content

Each of the factors included in the classification trees was consistent with potential risk markers for suicide ideation identified in the extant literature (e.g., Evans et al., 2004; Feigelman & Gorman, 2008; Kerr et al., 2006; Wong, Brower, & Zucker, 2011). However, interpretations made based on the content of the classification trees should be made within the framework of CTA. Each decision point, or split, occurs within a specific portion of the overall sample, as defined by the previous decision points of the classification tree. This results in the selection of unique subsamples, which may not be directly comparable with the extant literature.

For example, the first split was a history of suicide ideation at Wave 1, consistent with previous literature in which past suicide ideation serves as a predictor of future ideation (e.g., Gould et al., 2003). Tree 5, however, includes a split based on ethnicity, with those who endorsed being Hispanic having a lower likelihood of reporting suicide ideation at Wave 2 than did those who did not endorse being Hispanic. Existing evidence has largely supported the reverse conclusion, with the preponderance of data indicating a higher rate of suicide ideation among Hispanic adolescents compared with their non-Hispanic peers (e.g., Kann et al., 2016a, 2016b). This seemingly contradictory finding should be interpreted within the framework of CTA: Among adolescents without a history of suicide ideation in the previous 12 months, with at least mildly elevated depressive symptoms, no history of family suicide attempt, and low perceptions of social support, those of Hispanic ethnicity had a lower risk of reporting suicide ideation at Wave 2 than had those not of Hispanic ethnicity. This complex intersection of risk markers should not necessarily be construed as contradictory to existing empirical data, which has rarely accounted for interactions among risk markers. Further research will be necessary to explore the nature of such findings before firm conclusions can be drawn.

### Limitations and Future Directions

The findings should be interpreted in light of the study’s strengths and limitations. Strengths of the study include its prospective design and large sample, allowing for the prediction of suicide ideation over time. Another strength is the focus on prediction of onset of suicide ideation among adolescents without a history of past suicide ideation. Limitations include a reliance on self-report measures, which may be subject to social desirability



bias or other reporting biases. Although adolescent gender was included in the CTA analysis, it is possible that risk markers for suicide ideation differ for adolescent boys and girls, as they do for suicide attempts (e.g., King, Jiang, Czyz, & Kerr, 2014), but that was not explicitly tested in this study. Another limitation includes the use of single-item indicators for many of the independent variables and reliance on indicators available in the data set. These indicators served as “proxy” variables for broader constructs and may not accurately reflect the nuance of the larger constructs. That is, although single-item indicators provide an efficient means of assessing domains of risk, they may fail to fully capture the breadth of the construct. Future research is needed to replicate these findings using full, validated measures. Further, the Add Health data from Waves 1 and 2 were collected between 1994 and 1996. As a consequence, it is possible that cohort effects are present and that adolescents today might interpret these items differently.

At times, CTA may be subject to influence by idiosyncrasies in the data from which classification trees are derived, leading to difficulty replicating the predictive accuracy of the classification trees. To improve the likelihood of replication within this study, a 10-fold cross-validation procedure was utilized in which each classification tree was created 10 times, each time with a random subset of the data removed. The trees presented here are the result of pruning inconsistent results across the 10 replications, which serves as a means of reducing minor, sample-specific branches in the classification trees. However, future research should validate these classification trees using independent samples prior to their utilization as screening tools. Additionally, classification trees do not provide clear guidelines for selecting which preventive interventions to implement (e.g., interventions to reduce depressive symptoms, increase emotion regulation skills, or teach problem-solving skills). The splits of the classification trees may be indicative of modifiable risk markers, but the classification trees do not imply causal links between risk markers and suicide ideation. However, the classification trees may provide a starting point for selecting appropriate interventions. For example, the LEAP intervention resulted in reductions in depressive symptoms and thwarted belongingness among adolescents (Hill & Pettit, 2016), and adolescents bereaved due to suicide may benefit from grief-focused interventions (e.g., Layne et al., 2008).

## Conclusions

The present study provided a data-driven model to assist community organizations in prospectively identifying adolescents at risk for suicide ideation. A classification-tree approach was used to identify adolescents who reported suicide ideation 1 year after a baseline assessment. Classification trees provided three distinct solutions with varying degrees of sensitivity and specificity for identifying adolescents who reported suicide ideation. The prospective identification of adolescent suicidal ideators offers an added opportunity for administering preventive interventions. Available screening tools focus on identifying risk based on concurrent suicide ideation but do not prospectively identify suicidal ideators. For organizations interested in suicide prevention, these models provide a means for screening adolescents and directing them to appropriate interventions. For use as a screening tool, the

various classification trees offer organizations options for instituting large-scale screenings for suicide-ideation risk.

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