THESIS

# USING MACHINE LEARNING AND COHORT-SEQUENTIAL MODELING TO PREDICT SUICIDE ATTEMPTS AMONG COLORADO ADOLESCENTS

Submitted by

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# ABSTRACT

## USING MACHINE LEARNING AND COHORT-SEQUENTIAL MODELING TO PREDICT SUICIDE ATTEMPTS AMONG COLORADO ADOLESCENTS

Suicide has become a leading cause of death across the United States with adolescents posed at particular risk for engaging in self-harm and suicidal ideation, plans, and attempts. As the number of suicide attempts increases, the greater the likelihood that someone will continue attempting suicide, incur an injury during one of their attempts, or die by suicide also increases. Although researchers have identified individual predictors of suicide, very few have investigated the intersectional and interacting variables that predict suicide attempts while differentiating the predictors of multiple suicide attempts from predictors of single attempts and those who have not attempted suicide. The present study utilized the exploratory classification trees to identify these predictors of multiple suicide attempts across the 2015, 2017, and 2019 Healthy Kids Colorado Surveys, which assesses the health and safety of Colorado adolescents.

The present study sought to identify if the predictors of multiple suicide attempts change over time and for participants with expansive transgender identities and/or sexual orientation. Models identified 26 predictors of multiple suicide attempts with creating a plan for suicide in the last year as the most predictive of multiple suicide attempts, followed by the number of times participants used heroin in their lifetime, the number of times in the past month when participant misused prescription medications, and the number of days in the last month when participants smoked cigarettes. Results support the use of classification trees in identifying risk factors for multiple suicide attempts though replication is necessary to support these findings.

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# Chapter 1 - Literature Review

The World Health Organization (WHO, 2023) posits that over 700,000 individuals worldwide die by suicide every year. In 2021 alone, it was estimated that 48,183 individuals in the United States of American died by suicide (American Foundation for Suicide Prevention, 2023). These incident rates highlight only one portion of the greater concept that is suicide. For example, the rates of self-harm along with suicidal ideation, plans, and attempts have all been increasing across the United States of America since 1999 (Centers for Disease Control and Prevention [CDC], 2020). Additionally, there are countless loved ones and friends of individuals facing suicide and self-harm who are also indirectly confronting suicide. Therefore, it is imperative that suicide and its prevention be treated as global health priorities moving forward (Bloch-Elkouby, 2020; WHO, 2018).

Adolescents are at a particularly elevated risk for engaging in self-harm and suicidal ideation, plans, and attempts (Mars et al., 2019). In fact, suicide is the second leading cause of death among individuals aged 10-24 in the United States of America (CDC, 2021a; WHO, 2023), and suicide rates increased 62% across 2007 to 2021 among individuals aged 10-24 (CDC, 2023a). It is suspected that increased smartphone and social media use may partially account for the increased suicide rates among adolescents (Twenge et al., 2018). Adolescents in Colorado are at an even greater risk for suicide. In 2021, Colorado ranked 3$^{rd}$ out of 50 states for highest rates of death by suicide for individuals aged 11-21 (CDC, 2023b). Adolescents form practices, habits, commitments, and relationships that that are echoed in future behaviors and interactions, including suicidal behaviors, making it imperative to understand suicidal behavior as it occurs during adolescence (Avison, 2010).

Research has repeatedly found that a previous suicide attempt is the strongest predictor of subsequent suicide attempts (Brown et al., 2000; Edgcomb et al., 2020; WHO, 2023). Relatedly, the likelihood that someone will engage in additional suicide attempt, incur an injury from suicide attempts, and die by suicide increases with each subsequent suicide attempt (Harris & Barraclough, 1997; Miranda et al., 2008). Despite the increasing suicide rates among adolescents in the United States of America (CDC, 2023a) and in Colorado specifically (CDC, 2023b), there remains a dearth of research studies investigating predictors of multiple suicide attempts among adolescents that are independent of predictors of single suicide attempts (Ezquerra et al., 2024; Mendez-Bustos et al., 2013). Therefore, the present study focused on identifying the epidemiological and etiological factors that predict multiple suicide attempts among Colorado adolescents.

**Predictive Models of Suicide**

Many of the current models that identify and predict future suicidal thoughts and behaviors rely on confirmatory factor analysis (CFA) to psychometrically support the predictive nature of the model (e.g., Carvalho et al., 2015; Hagstrom & Gutierrez, 1998; Joiner, 2005; Stickl Haugen et al., 2021; Witte et al., 2010). CFAs confirm the factor structure of the relation between preselected observed and latent variables (Agresti, 2017; Schreiber et al., 2006). Researchers conducting CFAs use theory and empirical support to hypothesize how a factor, or the underlying relation between variables, influences another set of preselected variables (Mvududu & Sink, 2013).

The Interpersonal-Psychological Theory of Suicidal Behavior (Joiner, 2005), one CFA model of suicide, posits that an individual will only die by suicide if they have (1) a desire to die by suicide and (2) the capability of taking their life. The former prerequisite for suicide is

comprised of both perceived burdensomeness and low belonging/social alienation (Joiner, 2005). These components combine to form a factor that researchers have used to predict suicidal behavior among individuals with severe suicidality (Joiner et al., 2009), physicians and veterinarians (Fink-Miller & Nestler, 2018), convicted criminal offenders (Cramer et al., 2012), undergraduate students with self-reported history of traumatic brain injuries (Bryson et al., 2017), military veterans and active military personnel (Castro & Kintzle, 2014), and young adults with depressive symptoms (Joiner et al., 2009), to name a few populations.

These CFA studies confirm the validity of the Interpersonal-Psychological Theory of Suicidal Behavior (Joiner, 2005) in predicting suicidal behavior, but there are many individual factors that also predict suicidal behavior that do not appear in the aforementioned model (e.g., previous self-injurious behavior (Edgcomb et al., 2020), assigned sex (Yıldız et al., 2018), gender (Choo et al., 2017), substance use (Chesney et al., 2014; Fazel & Runeson, 2020)). Therefore, it is advantageous to use exploratory factor analysis (EFA) to identify multiple individual variables and interactions among variables that best predict suicidal behavior. Contrary to the structured nature of CFAs, EFAs are deliberately unstructured and atheoretical, allowing researchers who utilize EFAs to explore and identify possible research questions and areas of interest that can be supported through later CFAs (Jaeger, & Halliday, 1998). EFAs identify the latent structures that explain the covariance between multiple variables (Agresti, 2017). The data utilized in EFAs is from heterogeneous samples so that (1) the results are generalizable and (2) to assure that the relation between variables and factors are evenly distributed across all scores of samples (Reio & Shuck, 2015; Widaman, 2012).

EFAs are conducted through multiple means, including machine learning. Machine learning is a combination of artificial intelligence and algorithm computations that rely on

surrounding data or the environment to explain and predict a specified outcome (El Naqa & Murphy, 2015). An EFA conducted through machine learning techniques identifies the optimal number of variables needed to create the factor/structure (Mvududu & Sink, 2013). There are no restrictions on the number of variables that can be included in an EFA conducted through machine learning because the analysis will distinguish the variables (either by themselves or in a chain/tree of interacting variables) that correlate with the factor from those variables that do not correlate (Kahn, 2006).

Machine learning has recently emerged as a vital tool in exploratory clinical research because of its ability to handle large and complex datasets while simultaneously identifying both interactions between variables and intersections of sociodemographic identities that put individuals at risk for multiple suicide attempts (Ley et al., 2022; Morina et al., 2020). Machine learning is a combination of computations and artificial intelligence that can be used in research and clinical practices to diagnose and predict future outcomes (Lin et al., 2020). Classification trees (CTs), one specific type of machine learning, is an explanatory analysis that allows researchers to run simultaneous analyses on multiple predictor variables to determine their relation to a preidentified outcome variable (Strobl et al., 2009; Wallace et al., 2019; Zhang & Singer, 2013). CTs run best with moderate to large samples sizes (e.g., 50 or more participants), with multiple variables that are endorsed by 50 or more participants, and heterogeneity across the sample in order to verify that the results are statistically sound and generalizable (Agresti, 2017; Finch & Finch, 2016; Reio & Shuck, 2015; Widaman, 2012). Therefore, it is advantageous for researchers to utilize large datasets with multiple variables when conducting machine learning classification trees.

CTs were deliberately selected for the present study given their exploratory and atheoretical yet supervised designs. Namely, CTs have no prespecified theory and expectations about the relations between the predictor variables and the outcome variable, allowing the model to freely explore all possible relations between these variables before identifying the independent, interactional, and intersectional variables that optimally predict the outcome variable of interest without proposing causality between these variables (Gonzalez, 2021; Leclerc, 2009; Ware et al., 2022). The variables that are identified as salient predictors of the outcome variable are then ranked in order of their importance, with higher ranked variables being stronger predictors of the outcome variable (Protopopoff et al., 2009; Therneau & Atkinson, 1997; Ware et al., 2022). After exploring and establishing relations between variables through CTs, confirmatory research can then be conducted to support or refure the findings of the exploratory study (Jaeger, & Halliday, 1998). The exploratory yet supervised approach to CTs is ideal for the present study given the limited amount of research that exists on predicting multiple suicide attempts among adolescents (Ezquerra et al., 2024; Mendez-Bustos et al., 2013).

The CTs implemented in the present study are considered supervised because each of the trees learns by example. In other words, the dataset on which the CT is going to be run is split into a training and testing subsets (Gonzalez, 2021). The training subset is used to train or teach the CT to optimally and accurately predict the outcome variable of interest through tuned stopping rules that prevent the tree from being unnecessarily complex and overfit (e.g., establishing the minimum required predictive improvement to the tree to include a variable in the tree, specifying the number of observations that are necessary to institute a split in the tree, requiring a minimum number of observations necessary to end a branch of the tree; Therneau & Atkinson, 1997; Wallace et al., 2020; Ware et al., 2022). Once the stopping rules have been

established and the CT is trained, the same stopping rules are then implemented in the testing subset of the data to determine how effective the CT will be in accurately predicting the outcome variable in this new subsample with the intention of being able to see how generalizable the CT will be to novel samples (Gonzalez, 2021; Hellemann et al., 2009). Research shows that CT models are often dominated by proximal predictors (e.g., Edgcomb et al., 2021; Wallace et al., 2020). Therefore, it is auspicious for researchers to explore the strength of proximal and distal predictors in their individual categories as well as together when investigating predictors of an outcome. Through the utilization of large datasets like the one used in the present study, CT modeling allows researchers to identify individual and combinations/interactions of predictors, automatically selected by the machine, that are optimized for a clinical outcome (Edgcomb et al., 2021).

**Intersectionality and Variable Interactions**

As noted thus far, previous research on suicide has focused on pathological indicators and individual identity factors that protect against and predict future suicidal thoughts and behaviors (including suicide attempts). This approach to suicide prevention has limited capacity for thwarting increasing rates of suicidal thoughts and behaviors (Hjelmeland & Knizek, 2016; Nock, 2016). The statistical models that identify individual risk factors for suicide circumvent the nuanced interactions between individual risk factors. For example, the Interpersonal-Psychological Theory of Suicidal Behavior (Joiner, 2005) does not address how in the year following hospitalization, prior suicidal behavior, being under the age of 55, having an alcohol use disorder, and having a medical comorbidity indicate the highest risk for future readmission into the hospital (Edgcomb et al., 2020).

Another study investigating the psychological autopsies of adolescents who died by suicide found that male adolescents who met the criteria for a substance use disorder were six times more likely to die by suicide compared to community samples (Brent et al., 1993). In the same study, females who were diagnosed with substance use disorders were at no greater risk for dying by suicide compared to community samples. Suicidal ideations, which are often a precipitating factor for suicide attempts, can be caused by high mental stress, but traditional statistical methods show only moderate correlations between these two variables (Lin et al., 2020). These findings indicate that current models of detecting risk factors for suicide may be too restricted to capture the interactions between multiple suicide risk factors, prompting the utilization of more advanced statistical models to best capture these interactions in the present study.

In addition to failing to capture the interactions between variables that put individuals at risk for attempting suicide, traditional statistical methods are also not well suited to identify the intersectionality of individuals who may be at highest risk for multiple suicide attempts. With roots in the Black Feminist movement and Sojourner Truth's 1851 speech, "Ain't I a Woman?" (Brah & Phoenix, 2004), intersectionality was formally defined by Kimberlé Crenshaw (1991) as the unique ways in which race and gender interact to shape the experiences of individuals whose gender and race have been minoritized by society individually (e.g., Black women). Although definitions of intersectionality have evolved over the years, intersectionality denotes the health and social inequalities that are rooted in different sociodemographic identities, such as ethnicity, race, gender, age, sex, socioeconomic status (Bauer, 2014; Hankivsky & Grace, 2015). Individuals who identify as having one or more non-dominant sociodemographic identities report experiencing higher rates of suicidal thoughts and attempts compared to counterparts with

dominant socio-demographic identities (King et al., 2020; Merikangas et al., 2010). Unless a research sample has been limited to a small number of sociodemographic identities that can be combined to create few intersections, previous research studies lack the statistical complexity and sample size necessary to investigate the role of intersectionality as a risk factor for suicide.

The present study investigated interaction terms in all statistical analyses to highlight the influence of intersectionality in suicide attempt prevention, thus increasing the external validity of the predictive suicide models. Given the number of variables and possible interactions that were explored in the present study, it was imperative to classify variables into meaningful categories to streamline comparisons across analyses (Bloch-Elkouby, 2020). The present study relied on a framework that categorized predictors of multiple suicide attempts into distal and proximal predictors.

## Distal Predictors of Future Suicide Attempts

Distal predictors are chronic or long-term factors that predispose individuals to contemplating and/or attempting suicide in the future (Cohen et al., 2018; Jobes et al., 2015; Tucker et al., 2015). Distal predictors of future suicide attempts include trait-like social, psychological, and interpersonal factors (e.g., age, race, ethnicity, assigned sex, gender, sexual orientation, personality traits) along with historical or chronic vulnerabilities (e.g., history of forced sexual encounters, previous suicide attempts and self-harm, history of mental health symptoms; Bloch-Elkouby et al., 2020; Chan et al., 2016; King & Merchant, 2008; Nock et al., 2010; Oquendo et al., 2006).

### *Age*

Thoughts of suicide and the intent to engage in suicidal behavior vary across years, days, and even hours of time, demonstrating that suicide risk varies across the lifespan (CDC, 2021a;

Hallensleben et al., 2019; Kleiman et al., 2017). Although individuals over the age of 45 in the United States of America are at the highest risk for dying by suicide (Wasserman et al., 2021), suicide was the second leading cause of death for individuals aged 10-14 and the third leading cause of death for individuals aged 15-24 in the United States of America in 2020 (CDC, 2021a). The later ages include the formative adolescent years (10-19 years of age; WHO, 2021). Suicide ideation is infrequent among adolescents aged 10-14 (Wasserman et al., 2021), and the rates of suicide ideation gradually increase throughout the later adolescent years (15-19 years of age; Borges et al., 2012). Similarly, deaths by suicide are relatively rare for adolescents under the age of 14 (0.93 per 100,000) and increase between 15 and 19 years of age (6.04 per 100,000; Glenn et al., 2020). It is possible that deaths by suicide occur more often for adolescents under the age of 15 but few studies investigate the number of deaths by suicide for individuals in this age range (Dervic et al., 2008; Soole et al., 2015). It may also be the case that coroners are hesitant to assign suicide as a cause of death for adolescents under the age of 15, thus perpetuating lower suicide rates among this population (Hawton & James, 2005). Therefore, it is essential to accurately identify the age at which adolescents are most likely to begin attempting suicide.

***Race and Ethnicity***

For the purposes of this study, non-dominant racial and ethnic identities in the United States of America are defined as any racial and ethnic group that is underrepresented in education, employment, media, research, and popular culture. Examples of identities that are considered non-dominant in the United States of America include individuals who identify as Hispanic or Latino/a/x, Black, African American, American Indian, Alaskan Native, Asian, and Pacific Islander among many additional identities. Individuals who self-identify as having one or more non-dominant identities are often at increased risk for negative mental health outcomes,

negative physical health outcomes, and abbreviated mortality (Baker et al., 2010). For instance, individuals who self-identify as having one or more non-dominant identities endorse the highest rates of suicide (WHO, 2023). Specifically, non-Hispanic/Latino/a/x American Indian or Alaskan Native males and females showed the greatest increase in suicide rates in the United States of America in 2017, increasing by 139% for females and 71% for males (Curtin & Hedegaard, 2019).

Individuals who identify as Hispanic/Latino/a/x, non- Hispanic/Latino/a/x Asian or Pacific Islander, and non- Hispanic/Latino/a/x American Indian or Alaskan Native have historically been misclassified into a catchall category, often labeled "other" racial and ethnic groups, resulting in the underestimation of the number of suicide attempts and deaths in these groups (Arias et al., 2016). Furthermore, it is difficult to collect rare outcome data, such as suicide rates, on these distinct racial and ethnic groups because the populations are much smaller (Balzer et al., 2016). Some researchers note that many individuals who identify as having one or more non-dominant racial and ethnic identities report higher rates of suicidal thoughts and attempts because these individuals do not have access to adequate and affordable mental health services, resulting in underlying mental health complications intensifying to the point of suicidal thoughts (e.g., King et al., 2020; Merikangas et al., 2010). Individuals with non-dominant racial and ethnic identities, compared to White individuals, are also more likely to be diagnosed with post-traumatic stress disorder after being exposed to racial trauma, discrimination, stressors, and dangerous race-based events (Abram et al., 2004; Pole et al., 2008; Roberts et al., 2011; Saleem et al., 2020). These trauma responses have been indirectly linked to increased suicidal ideations and attempts among youth with non-dominant racial and ethnic identities (Polanco-Roman et al., 2021).

### *Sex, Gender, and Sexual Orientation*

The rates at which individuals experience suicidal thoughts and attempts as well as deaths by suicide vary by gender and sex. Although some studies report no differences across gender for adolescents who engage in both suicidal and non-suicidal self-injurious thoughts and behaviors (e.g., Baetens et al., 2011), these result stand in contrast to multiple sources purporting that women across multiple countries report thinking about and attempting suicide 2-4 times more often than men and that men are more likely to die by suicide compared to women (Carretta et al., 2023; Glenn et al., 2020; Wasserman et al., 2021; Yıldız et al., 2018). None of the aforementioned research teams discussed presenting participants with options for sex and gender beyond dichotomous categories (e.g., male and female to represent assigned sex and woman and man to represent gender identity). One explanation for this gendered difference is that attempting suicide is considered a masculine behavior that would be inappropriate for women who value their femininity (Kushner 1993, 1995; Scotti Requena et al., 2022). Another explanation for these gendered differences is that females may be exposed to more suicidal behavior over social media outlets compared to their male counterparts (Twenge et al., 2018).[1]

In their study utilizing classification tree analyses to identify the correlates of self-injurious thoughts and behaviors across gender identities over four sets of data collection, Wallace et al. (2020) found that heavy alcohol use, trauma, and disordered eating were predictive of self-injurious thoughts and behaviors for women, whereas beliefs about alcohol use among their peers was an important predictor of self-injurious thoughts and behaviors among men (Wallace et al., 2020). In their study investigating the suicidal behavior of adolescents, Toomey

[1] Male and female were the only categories of assigned sex presented in this study, and the researchers did not appear to collect data on gender.

et al. (2018) found that adolescents who identified as “transgender – female to male,” “transgender – not exclusively male or female,” “transgender – male to female,” or “questioning” all reported higher rates of suicide attempts compared to adolescents who identified as “female” or “male.” These studies indicate that gender identity may be both a significant predictor and moderating variable for suicide attempts.

In the present study, gender and sexually expansive identities were defined as any sexual/affective orientation and gender identity historically minoritized by the larger society in the United States of America (e.g., gay, bisexual, lesbian, polyamorous, asexual, pansexual, transgender, transwoman, transman, genderqueer, gender fluid, demiboy, and demigirl, among other orientations and identities; Dean, 2011; Johns et al., 2021). Cisgender is defined as individuals whose assigned sex and gender expression match (Trans Student Education Resources, 2023). Heterosexuality is defined as the sexual orientation/preference for individuals who are sexually and/or affectionally attracted to individuals of the opposite sex (American Psychological Association, 2021).

Individuals who self-identify as gender and sexually expansive endorse higher rates of self-injurious thoughts and behaviors compared to individuals who self-identify as cis-gender and/or heterosexual (Choo et al., 2017; Hill et al., 2022; Whitlock et al., 2011). Specifically, bisexual men and women and gay men report a higher frequency of suicidal thoughts compared to women and men who identify as heterosexual (Nystedt et al., 2019). Self-reporting as sexually expansive (e.g., bisexual, lesbian, or gay) increases the risk of attempting suicide for adolescents who also identify as gender expansive (e.g., transgender, genderqueer, or questioning) but not adolescents who identify as cisgender (Toomey et al., 2018).

### *Forced Sexual Intercourse*

The Centers for Disease Control and Prevention (2021b) define sexual violence as any sexual encounter during which consent is coerced or not provided. They go on to identify that one in four men and one in three women will experience sexual violence during their lifetime. The Rape, Abuse, Incest National Network (RAINN, 2023) posit that someone in the United States of America is sexually assaulted every 68 seconds, and someone under the age of 18 is the victim of sexual violence every 9 minutes. Furthermore, 66% of individuals who experience sexual violence are between the ages of 12 and 17, highlighting that older adolescents are at elevated risk for experiencing sexual violence (RAINN, 2023; U.S. Department of Justice, Office of Justice Programs, 1997).

Adolescents who experience sexual violence can potentially encounter lifelong effects on their well-being, health, and opportunities (CDC, 2021b). Sexual violence during adolescence has also been linked to poor academic performance (Kearns & DiRienzo, 2023; Macmillan & Hagan, 2004), self-harm (Bentivegna & Patalay, 2022; Noll et al., 2003), sexual risk-taking behavior (Holt et al., 2018; Lang et al., 2011), post-traumatic stress disorder (Boumpa et al., 2022; Kilpatrick et al., 2003), substance misuse (Kilpatrick et al., 2000; Mintz et al., 2022), and depression (Bentivegna & Patalay, 2022; Danielson et al., 2005), among many other outcomes. Many of the aforementioned effects of sexual violence are independent predictors of suicidal thoughts and behaviors (e.g., Edgcomb et al., 2020; Walsh et al., 2018) and serve as covariates of suicidal thoughts and behaviors when investigating the predictive nature of sexual violence on the same outcome. Sexual violence during adolescence also operates as an independent predictor of suicidal thoughts and attempts (Anderson et al., 2014; Bentivegna & Patalay, 2022).

### *Previous Self-Injurious Behavior*

The most predictive risk factor for future suicide attempts is previous self-injurious behaviors, both with and without the intention of dying (Edgcomb et al., 2020; WHO, 2023). In their study on Flemish adolescents aged 12-18, Baetens et al. (2011) found that over 13% of adolescents engage in non-suicidal self-injury (e.g., cutting, burning, or head banging without the intention of dying by suicide) and just under 4% engage in suicidal self-injury (e.g., hanging, cutting, or choking with the intention of dying by suicide). It is estimated that 18% of individuals who engage in suicidal thoughts and behaviors will repeat that behavior within one year (Hawton et al., 2007; Qian et al., 2023) and up to 40-60% of individuals who have died by suicide engaged in non-suicidal self-harm before their death (Owens et al., 2002). Non-suicidal self-injury, active suicidal thoughts (e.g., "I want to die"), passive suicidal ideations/suicide gestures ("If I died in a car accident, that would be OK"), and suicidal planning have been identified as correlates of suicide attempts among adolescents (Burke et al., 2020). It is estimated that 33% of adolescents who experience suicidal ideations go on to develop a plan for suicide, and 60% of those adolescents who develop a plan for suicide will attempt suicide (Nock et al., 2013). Adolescents who have engaged in previous suicidal thoughts and behavior are between 1.5- and 2-times more likely to die by suicide than those who have not engaged in previous suicidal thoughts and behaviors (Castellví et al., 2017; McLoughlin et al., 2015; Ribeiro et al., 2016). Approximately 25% of adolescents who attempt suicide will have one more suicide attempt within one year of the first attempt, indicating that timing is an important factor in being able to predict future suicide attempts among adolescents (Hulten et al., 2001).

### *Mental Health Symptoms*

Research suggests that anywhere between 19% and 70% of individuals who died by suicide saw either a healthcare provider (19%) or mental health professional (50-70%) one month before the death by suicide (Chang et al., 2011; Luoma et al., 2002). Many of the remaining individuals who contemplate and/or attempt suicide and do not seek help, do so in part because of the stigma surrounding suicide and related mental health disorders (Jacobson et al., 2020; WHO, 2023). Simply seeing a provider is not enough to thwart a future suicide attempt because the majority of individuals who attempt suicide and see a provider before the attempt either deny or do not discuss their suicide ideations during sessions (CDC, 2021a; Louzon et al., 2016). Therefore, researchers and clinicians must utilize more comprehensive risk assessments that identify both suicidal ideations and related mental health symptoms that are predictive of suicide attempts (Bloch-Elkouby et al., 2020).

One mental health symptom that has been repeatedly predictive of suicidal thoughts and behaviors is depression (e.g., Wallace et al., 2020; Walsh et al., 2018; WHO, 2023). Adolescents in the United States of America have increasingly reported depressive symptoms since 2010 (Twenge et al., 2018; WHO, 2023). Adolescents are at greater risk for developing depression when they have a low attachment to their parents compared to children with no attachment to their parents, suggesting that a strained relationship with a parent may be more harmful for adolescents than no relationship with their parent (Kent & Bradshaw, 2020). Therefore, depressive symptoms serve as both a direct and indirect variable that predicts suicidal thoughts and behaviors among adolescents.

## Proximal Predictors of Future Suicide Attempts

Proximal predictors of suicide are immediate, short-term factors that predispose individuals for contemplating and/or attempting suicide in the future (Bagge & Sher, 2008; Berman, 2018; Fawcett at al., 1990; Rudd et al., 2006). Proximal predictors of future suicide attempts include acute psychological markers (e.g., recent upsetting events and depressive symptoms; Brent et al., 1993; Hendin et al., 2007) and recent experiences (e.g., substance use and sexual behavior; Bloch-Elkouby et al., 2020; Glen & Nock, 2014; King & Merchant, 2008).

### *Substance Use*

Both substance use and self-injurious thoughts pose serious general health concerns among adolescents (Rahal et al., 2023; WHO, 2023). Although the minimum age to buy nicotine products in most states is 18 years old, the percentage of adolescents in the United States of America who endorsed using electronic cigarettes (e-cigarettes or vaping) daily was 27.6% with 42.3% of students using e-cigarettes on 20 or more days per month (CDC, 2022). These numbers continue rising despite the fact that nicotine and vaping have been associated with hazardous health outcomes (e.g., respiratory damage, cardiovascular distress, and depression) that increase one's risk of suicidal thoughts and attempts (Boudi et al., 2019; Gostin & Glasner, 2014). Therefore, it is suspected that nicotine use and vaping are predictive factors of multiple suicide attempts.

Alcohol use has been repeatedly identified as a risk factor for self-injurious thoughts and behaviors, including suicide attempts (WHO, 2021). Heavy alcohol use, which was defined as fewer protective behavioral strategies and increased negative consequences from drinking, and perceived norms regarding the alcohol use of same-gender peers appear as salient predictors of suicidal thoughts and behaviors for both women and men, respectively (Wallace et al., 2020).

Individuals with alcohol use disorders are at greater risk for engaging in self-harm and attempting suicide following a medical hospitalization (Edgcomb et al., 2020). The psychological autopsies of adolescents who died by suicide revealed that 22% of adolescents met the criteria for an alcohol use disorder at the time of their death by suicide (Shaffer et al., 1996). These studies highlight the importance of investigating alcohol use as a predictive factor for multiple suicide attempts in the present research study.

Illicit drugs, such as methamphetamine, cocaine, ecstasy, heroin, inhalants, and hallucinogens, are defined as substances that are illegal to buy, sell, and consume and/or that are highly additive in nature (Addiction Center, 2023). In some states, cannabis is outlawed, thus classifying it as an illicit drug. Cannabis is legal in Colorado for those who are 21 years of age and individuals who are 18-years-old and possess a medical cannabis card. Because the present study was conducted with individuals under the age of 18 in Colorado, cannabis was considered an illicit substance for participants who endorsed using the substance. Researchers found that adolescents who died by suicide or seriously attempted suicide were up to nine times more likely to use illicit drugs compared to adolescents who never attempted suicide and those who attempted suicide but did not die by suicide (Brent et al., 1993; Romanelli et al., 2022). Similarly, 13% of adolescents who died by suicide qualified for an illicit drug abuse diagnosis at the time of their death by suicide with the greatest risk being for those with opioid and sedative/hypnotic use disorders (Crump et al., 2021; Shaffer et al., 1996). These studies highlight the importance of investigating all substance use as potential predictors of multiple suicide attempts.

### *Sexual Behavior*

Alfred Kinsey and his colleagues statistically identified that adolescents and adults were increasingly engaging in premarital sexual behavior for pleasure, exploration, and mate selection (Kinsey et al., 1948; Kinsey et al., 1953). Modern researchers have continually supported Kinsey's claim that adolescence is a time of development – including sexual development (e.g., Feldmann & Middleman, 2002; Koch, 2020). In 2019, 46% of high school students in the United States of America reported engaging in sexual intercourse, thus supporting that sexual behavior during adolescence is relatively prevalent (CDC, 2020).

Although it is a normal part of development, there are ramifications for engaging in sexual behavior at a young age. For example, adolescents who engage in sexual behavior are at risk for experiencing sexual violence at some point during their lifetime (CDC, 2021b). Adolescents are also more likely to develop mental health disorders and experience distress as a result of being psychologically unprepared to manage sexual relationships (Cauffman & Steinberg, 2000; Prendergast et al., 2019). Sexual behavior during adolescence is also linked to increased suicide risk. Specifically, adolescents who engaged in any sexual behavior are more than two times more likely to think about and attempt suicide compared to adolescents who abstain from sexual behavior during adolescence (Hallfors et al., 2004; Smith et al., 2020). Additionally, adolescents who had intercourse for the first time between the ages of 12 and 14 are at higher risk for experiencing suicidal thoughts and attempting suicide (Mota et al., 2010). Adolescents and adults who report having two or more sexual partners in their lifetime are also more than 1.5 times more likely to attempt suicide compared to individuals with only one sexual partner (Mota et al., 2010; Smith et al., 2020). These findings support the exploration of sexual variables as predictors of suicide attempts in the present study.

## Machine Learning

Machine learning has recently emerged as a vital tool in exploratory research because of its ability to handle large and complex datasets while simultaneously identifying both interactions between variables and intersections of sociodemographic identities that put individuals at risk for multiple suicide attempts (Ley et al., 2022; Morina et al., 2020). Machine learning is a combination of computations and artificial intelligence that can be used in research and clinical practices to diagnose and predict future outcomes (Lin et al., 2020). Classification trees (CT), one specific type of machine learning, is an explanatory analysis that allows researchers to run simultaneous analyses on multiple predictor variables to determine their relation to a preidentified outcome variable (Strobl et al., 2009; Wallace et al., 2019; Zhang & Singer, 2013). CT modeling also allows researchers to identify a combination/interaction of predictors, automatically selected by the machine, that are optimized for a clinical outcome (Edgcomb et al., 2021).

## Research Aims

It is evident from these previously mentioned studies that there is heterogeneity across risk factors and predictors for multiple suicide attempts. Therefore, it is imperative to understand the nuances between individuals that place them at higher or lower risk for multiple suicide attempts (Jacobson et al., 2020; Wallace et al., 2020; Walsh et al., 2018). By investigating the intersectional and interactional epidemiological and etiological risk factors of suicide attempts, researchers can improve the identification and understanding of which adolescents will be most likely to attempt suicide multiple times in the future.

Based on the previous research studies, the following research questions were investigated in the present study:

1. Which sociodemographic identities and health risk behaviors (determined by endorsement of these behaviors), when interacting and intersecting statistically, are most salient in the prediction of more than one suicide attempt in Colorado adolescents aged 12-18 when compared to individuals who never attempt suicide and those who only attempted suicide one time?
2. Will the classification trees for each year of data collection (2015, 2017, and 2019) among Colorado adolescents aged-12-18 be comprised of different interacting and intersecting variables that are most salient in predicting multiple suicide attempts, indicating that the salience of specific predictors varies overtime?
3. Do the relations between the statistical interactions and intersections identified in the first research aim and multiple suicide attempts differ for individuals who identify as holding at least one non-dominate sociodemographic identity in the categories of transgender identity (transgender, not transgender, unsure, do not understand the question) and sexual orientation (heterosexual, lesbian/gay, bisexual, Not Sure)?

# Chapter 2 - Method

## Participants

Participants, aged 12 to 18, were recruited during the fall of 2015, 2017, and 2019 to participate in the study, creating a cohort sequential design. In total, 109,653 Colorado high school adolescents participated in this study, and the sample size for each academic year is as follows: $N_{2015}$ = 15,970; $N_{2017}$ = 47,146; and $N_{2019}$ = 46,537. The average participant age across all three datasets was 15.66 (*SD* =1.22). There were 54,272 (50.14%) participants who identified as female and 53,965 (49.86) participants who identified as male in the present study. In total, 95,707 (91.47%) participants in the present study never attempted suicide, 4,569 (4.38%) participants attempted suicide once, and 4,354 (4.16%) participants attempted suicide multiple times. See Table 1 for summary of participant characteristics across each dataset and totaled.

## Questionnaire

The data for the present study was obtained from the Healthy Kids Colorado Survey, which is a state-wide, biennial health and wellness survey offered to Colorado adolescents (CDPHE, 2020). The survey is funded and completed by the Colorado Departments of Education, Public Health and Environment, Public Safety, and Human Services; Colorado School of Public Health at the University of Colorado Anschutz Medical campus; and more than 30 organizations that form a community advisory committee. During odd numbered years, professional researchers select random Colorado schools, classrooms, and students to anonymously complete the survey. Because of the random selection process, the schools that participate in the survey vary across each year of data collection in terms of where they are located across the state of Colorado (urban, suburban, rural communities), school size, average

**Table 1**

*Participant Characteristics*

| Participant Characteristics | *2015* *N* (%) | *2017* *N* (%) | *2019* *N* (%) | *Total* *N* (%) |
|---|---|---|---|---|
| Age (range = 12–18) | *M* = 15.68 (*SD* = 1.22) | *M* = 15.62 (*SD* = 1.22) | *M* = 15.69 (*SD* = 1.21) | *M* = 15.66 (*SD* = 1.22) |
| Sex | | | | |
| Female | 7,987 (50.61) | 23,454 (50.19) | 22,831 (49.93) | 54,272 (50.14) |
| Male | 7,794 (49.39) | 23,273 (49.81) | 22,898 (50.07) | 53,965 (49.86) |
| Gender | | | | |
| Not Transgender | 14,236 (93.49) | 41,212 (95.23) | 42,688 (95.33) | 98,136 (95.02) |
| Transgender | 372 (2.44) | 558 (1.29) | 587 (1.31) | 1,517 (1.47) |
| Unsure of Transgender Identity | 233 (1.53) | 660 (1.53) | 667 (1.49) | 1,560 (1.51) |
| Do Not Understand the Question | 387 (2.54) | 845 (1.95) | 835 (1.86) | 2,067 (2.00) |
| Race | | | | |
| White | 11,483 (76.18) | 34,259 (75.49) | 34,040 (75.21) | 79,782 (78.48) |
| American Indian or Alaskan Native | 1,439 (9.55) | 4,094 (9.02) | 4,051 (8.95) | 5,533 (5.44) |
| Black or African American | 1,092 (7.24) | 3,136 (6.91) | 3,432 (7.58) | 7,660 (7.53) |
| Asian | 700 (4.64) | 2,662 (5.87) | 2,576 (5.69) | 5,938 (5.84) |
| Native Hawaiian or Other Pacific Islander | 359 (2.38) | 1,232 (2.71) | 1,158 (2.56) | 2,749 (2.70) |
| Ethnicity | | | | |
| Not Hispanic/Latinx | 10,296 (65.96) | 29,310 (63.20) | 29,762 (65.58) | 69,368 (64.61) |
| Hispanic/Latinx | 5,314 (34.04) | 17,069 (36.80) | 15,620 (34.42) | 38,003 (35.39) |
| Sexual Orientation | | | | |
| Heterosexual | 13,269 (86.67) | 36,808 (85.34) | 37,502 (83.89) | 87,579 (84.91) |
| Bisexual | 1,049 (6.85) | 3,268 (7.58) | 3,957 (8.85) | 8,274 (8.02) |
| Gay or Lesbian | 290 (1.89) | 1,038 (2.41) | 1,127 (2.52) | 2,455 (2.38) |
| Unsure of Sexual Orientation | 701 (4.58) | 2,018 (4.68) | 2,120 (4.74) | 4,839 (4.69) |
| Suicide Attempts | | | | |
| Never Attempted | 12,813 (91.27) | 41,573 (91.19) | 41,321 (91.83) | 95,707 (91.47) |
| Attempted Once | 617 (4.39) | 2,044 (4.48) | 1,908 (4.24) | 4,569 (4.38) |
| Attempted Multiple Times | 609 (4.34) | 1,979 (4.34) | 1,766 (3.92) | 4,354 (4.16) |

*Note*. The participant totals in each section varied due to both incidental and planned missingness in each Healthy Kids Colorado Survey.

socioeconomic status, dominant student demographics, access to academic and community resources, and political affiliations among students, staff, and the surrounding community, to name a few areas that vary across each year of data collection (CDPHE, 2020). Furthermore, schools are allowed to opt-in to participate in the biennial survey, and a greater number of schools in urban and suburban regions opt into the survey compared to schools in rural regions. The present study utilized data collected from 166 high schools across 49 counties in Colorado (CDPHE, 2020). To protect the anonymity of all participants and participating schools, all data from the survey is aggregated by the region in which it was collected. See the Appendix for depictions of the participant dispersion during each year of data collection based on the outcome variable in the present study.

The surveys were created by the Colorado School of Public Health (CSPH) survey team based on information that would identify the social, emotional, and physical health of Colorado adolescents at school and home (CDPHE, 2020). The number of questions in the surveys varied across each year of data collection depending on the variables identified as most indicative of the health and well-being of Colorado adolescents (CDPHE, 2020). The surveys also incorporated planned missingness in that there were two modules of each survey, creating six total surveys, to disperse the number of questions participants were asked. The surveys ranged from 102 to 126 total questions, and the present study focused on a subset of 36 questions from the larger surveys. Thirty-three of these questions were used during every year of data collection. Two questions were only used in 2015 but not in 2017 nor 2019.

The outcome variable in the present study consisted of the question, "*During the past 12 months, how many times did you actually attempt suicide?*" (answer options include: "*0 times*," "*1 time*," "*2 or 3 times*," "*4 or 5 times*," and "*6 or more times*"). This question and its answer

options were identical in all three surveys. To best identify the participants at the greatest risk for attempting suicide multiple times, the answer options for the outcome variable were collapsed into the following categories: “no attempts,” “single attempt,” and “multiple attempts.”

All remaining variables in the study were categorized as either proximal or distal predictors of suicide. In the present study, proximal predictors of suicide were defined as immediate, short-term factors that place participants at higher risk for attempting suicide. Therefore, all survey questions that specifically stated a behavior occurred in the last 30 days were classified as proximal predictors. Additionally, questions without specified timelines that were statistically most likely to be recent behaviors for adolescents, such as substance use and sexual behavior, were classified as proximal predictors of suicide in the present study. Distal predictors of suicide were defined as chronic or long-term factors that place participants at higher risk for attempting suicide in the present study. All survey questions that assessed participants demographics (e.g., age, race, ethnicity, sex, gender identity, sexual orientation), mental health variables that extended beyond a 30-day timeline, and lifetime incidence of forced sexual encounters were classified as distal predictors of suicide because this items captured or had the potential to capture predictors that had been true for participants for multiple years.

There were six demographic questions ascertaining participant age, race, ethnicity, assigned sex, gender identity, and sexual orientation. Sample demographic questions included, “*How old are you?*” (answer options include: “*12 years old or* younger,” “*13 years old*,” “*14 years old*,” “*15 years old*,” “*16 years old*,” “*17 years old*,” and “*18 years old or older*”); “*What is your race? (Select one or more responses.)*” (answer options include: “*American Indian or Alaska Native*,” “*Asian*,” “*Black or African American*,” “*Native Hawaiian or Other Pacific Islander*,” and “*White*”); and “*Some people describe themselves as transgender when their sex at*

*birth does not match the way they think or feel about their gender. Are you transgender?*" (answer options include: "*No, I am not transgender*," "*Yes, I am transgender,*" "*I am not sure if I am transgender*," and "*I do not know what this question is asking;"* CDPHE, 2020). All six demographic questions were used in every survey and were categorized as distal predictors of multiple suicide attempts in the present study.

There were seven questions assessing participant frequency engaging in self-harm, suicidal thoughts, suicide plans, suicide attempts, and suicide injuries in the last 12 months; how often they have felt sad for two consecutive weeks over the last 12 months; if they have access to a trusted adult when they are experience poor mental health or stress; and if they experienced poor mental health within the last 30 days. Sample questions from this section of the survey included, "*During the past 12 months, how many times did you do something to purposely hurt yourself without wanting to die, such as cutting or burning yourself on purpose?*" (answer options include: "*0 times*," "*1 time*," "*2 or 3 times*," "*4 or 5 times*," and "*6 or more times*"); "*During the past 12 months, how many times did you actually attempt suicide?*" (answer options include: "*0 times*," "*1 time*," "*2 or 3 times*," "*4 or 5 times*," and "*6 or more times*"); and "*If you had a serious problem, do you know an adult in or out of school whom you could talk to or go to for help?*" (answer options include: "*Yes*," "*No*," and "*Not sure*;" CDPHE, 2020). The questions inquiring about the frequency of suicide injuries and having poor mental health over the last 12 months were only used in the 2015 surveys. The remaining questions were used in every survey. The question addressing how many times participants attempted suicide in the last 12 months was the outcome variable in the present study. The question investigating how often in the last 30 days participants have felt their mental health was bad was categorized as a proximal predictor of multiple suicide attempts. The remaining five variables addressing mental health and

suicide experiences were categorized as distal predictors in the present study because they span 12 months of experiences instead of recent experience (e.g., the last 30 days).

There were 18 questions assessing participants' experience with and use of alcohol, cannabis, and illicit drugs. Specifically, participants were asked in ten separate questions if they have ever used alcohol, cannabis, vaping, cocaine, hallucinogens, heroin, methamphetamine, illicit prescription drugs, and steroids during their lifetime. For example, "*During your life, how many times have you used methamphetamines (also called speed, crystal meth, crank, ice, or meth)?*" (answer options include: "*0 times*," "*1 or 2 times*," "*3 to 9 times*," "*10 to 19 times*," "*20 to 39 times*," and "*40 or more times;*" CDPHE, 2020). Participants were asked their age when first using cigarettes, alcohol, and cannabis in three questions. For example, "*How old were you when you used an electronic vapor product for the first time?*" (answer options include: "*I have never used an electronic vapor product*," "*8 years old or younger*," "*9 or 10 years old*," "*11 or 12 years old*," "*13 or 14 years old*," "*15 or 16 years old*," and "*17 years old or older*;" CDPHE, 2020). Participants were asked in five questions how many times they have used cigarettes, alcohol, cannabis, vaping products, and illicit prescription medications in the last 30 days. For example, "*During the past 30 days, on how many days did you have at least one drink of alcohol?*" (answer options include: "*0 days*," "*1 or 2 days*," "*3 to 5 days*," "*6 to 9 days*," "*10 to 19 days*," "*20 to 29 days*," and "*All 30 days*;" CDPHE, 2020). Participants were asked one question about how many times they have binged alcohol in the last 12 months ("*During the past 30 days, on how many days did you have 4 or more drinks of alcohol in a row (if you are female) or 5 or more drinks of alcohol in a row (if you are male)?*"); the answer options for this question spanned 0 to 20 or more days (CDPHE, 2020). All 19 questions addressing participants'

experience with and use of alcohol, cannabis, and illicit drugs were used in every survey and were categorized as proximal predictors of multiple suicide attempts in the present study.

There were three questions ascertaining if participants have ever had sexual intercourse, how old they were during their first sexual intercourse, and the number of sexual partners they had over the lifespan. For example, "*How old were you when you had sexual intercourse for the first time?*" (answer options include "*I have never had sexual intercourse*," "*11 years old or younger*," "*12 years old*," "*13 years old*," "*14 years old*," "*15 years old*," "*16 years old*," and "*17 years old or older*;" CDPHE, 2020). These three questions were used in every survey, and these variables were categorized as proximal predictors of multiple suicide attempts.

There was one question assessing whether participants have been physically forced into unwanted sexual intercourse ("*Have you ever been physically forced to have sexual intercourse when you did not want to?*"). The answer options for this question were "*Yes*" and "*No*" (CDPHE, 2020). This question was used in every survey. Because this question did not include a timeline, it was possible that participants could have been forced into unwanted sexual intercourse early in their lifetime. Therefore, this variable was categorized as a distal predictor of multiple suicide attempts.

**Procedure**

During the spring semester of odd numbered years, the superintendents for all public, private, and charter schools across the state of Colorado received a phone call or letter requesting that district participate in the Healthy Kids Colorado Survey. Schools received a monetary stipend and a results report that was specific to their school in exchange for participating (CDPHE, 2020). If the superintendent consented, the districts and principals under that superintendent were reached requesting consent to participate in the study (CDPHE, 2020).

A two-stage stratified cluster sampling method was used to select the schools that would participate in the Healthy Kids Colorado Survey for each year. The first stage consisted of the Colorado School of Public Health survey team contacting the schools that consented to participate in the study during the fall semester of odd-number years to obtain the names of teachers, course subjects, and classrooms that are active during specific periods during the day. Each classroom was assigned a number identifier that was included in a pool from which classrooms were randomly selected to participate in the final survey administration (CDPHE, 2020). At least two weeks before the survey was set to be administered, the parents and guardians of students in the randomly selected classrooms were contacted via letter to request their child's participation in the study. All classrooms that were online, special education, and classrooms in which most or all students did not speak English or Spanish were determined to be ineligible to participate in the study (CDPHE, 2020).

Teachers of the randomly selected classrooms were given instructional videos and verbal prompts to read to students before administering the survey. Each superintendent, school district, principal, parent, and student-participant could opt out of the anonymous survey at any time (CDPHE, 2020). Questionnaires were available in English and Spanish based on student-participant preference. Each school determined if they would like the survey to be administered online via Qualtrics or on paper using Scantron Corp. survey sheets. All Scantron Corp. sheets were collected by the Colorado School of Public Health survey team after the student-participants completed the survey. At the conclusion of each survey, the students were thanked for their participation and released back to their normal school activities (CDPHE, 2020).

## Analytic Plan

The present study utilized classification trees (CT) to identify the direct and interaction relations that were salient in predicting multiple suicide attempts among Colorado adolescents. CT modeling relies on artificial intelligence and computational algorithms to identify a combination of variables that are optimized to predict a specified outcome (Edgcomb et al., 2020). Recursive partitioning is an algorithm within CT modeling that creates smaller, homogenous subsamples out of larger, heterogeneous samples (the partitions) that will predict the outcome variable of interest (James et al., 2013; Strobl et al., 2009; Wallace et al., 2020). Recursive partitioning works by looking at individual predictors of the outcome variable and identifying an individual variable that best discriminates between the two possible answers in the outcome variable (Hellemann et al., 2009). Once that variable is identified, a small homogenous subsample is created through a split/partition in the tree that creates two branches—one branch that predicts the specified outcome variable and one branch that does not predict the outcome variable.

Recursive partitioning is utilized for all predictor variables in the model (the recursive aspect of the algorithm) to identify multiple variables that predict the outcome variable either independently or further down a branch created by another variable until multiple "terminal nodes," or the ends of the branches, are identified that best explain the outcome variable (Doove et al., 2014; Wallace et al., 2019). Because recursive partitioning evaluates every variable individually and multiple times, it is possible for a predictor variable to appear in a CT more than once as a predictor of the outcome variable (Hellemann et al., 2009). Each terminal node in a CT has the possibility to consist of multiple interacting or intersectional predictive variables, each

with their own branch in the tree, that best predict the outcome variable (Lin et al., 2020; Wallace et al., 2019).

Without any parameters, CT can include all variables necessary to explain the outcome variable, but doing so creates too many branches and terminal nodes. In other words, the tree is overfit to the outcome. To prevent overfitting, recursive partitioning utilizes stopping rules that limit the number of splits and a minimum number of incidents that are required to start a new branch while still allowing for the most variance explained; in other words, the stopping rules allow for the greatest amount of variance in the tree to be explained using the fewest number of splits (Wallace et al., 2020). Fixed stopping rules were utilized in every model in the present study to allow for direct comparisons to be drawn consistently across the models while also accounting for the rare outcome of suicide attempts without overfitting the classification trees (Therneau & Atkinson, 1997). The complexity parameter was one of the stopping rules, which is the minimum level of improvement to the relative error a split must make at a node to be included in the tree. In the present study, the initial complexity parameter was 0.0001. Additionally, the minimum number of observations necessary before a node was split was held constant at 75 observations, and the minimum number of observations necessary to establish a terminal node in the tree was 50 observations (Therneau & Atkinson, 1997). To improve the predictability of the trees, each sample was cross-validated 100 times to create smaller randomly resampled subsets of the original model sample to determine how well, on average, the tree performed with a new random sample (Hellemann et al., 2009).

The effectiveness of each CT was evaluated by multiple tree parameters, including the prediction error, cross validation error, standard error, sensitivity, specificity, and accuracy. The prediction error in CT is the cost of misclassifying the outcome variable; the prediction error

ranges from 0 to 1.0 with lower scores indicating both a lower cost to misclassifying outcomes and a greater amount of the variance in the sample being explained by the model (Loh, 2011). Cross validation error in CT is the cost of misclassifying the outcome variable on average in cross-validation samples; the cross validation error ranges from 0 to 1.0 with lower scores indicating both a lower cost to misclassifying outcomes in the cross validation samples and a greater amount of the variance in the cross validation samples on average being explained by the model (Diao & Yi, 2023). The standard error in CT represents how spread out the data is in the cross-validation samples, which then informs how generalized tree is to the larger population. When subtracted from and added to the cross-validation error, the standard error establishes a 95% confidence interval for interpreting the cross-validation error (Breiman et al., 1984).

A parsimonious model was reached when the cross-validation error for a classification tree was lowest and had the fewest number of splits. Furthermore, the one-minus standard error rule was also implemented to prevent overfitting (Breiman et al., 1984). For the models restricted to those with non-dominate transgender and sexual orientation identities where the cross-validation confidence interval included 1.00, the model was considered overfit to the present. To reduce erasure of these non-dominate identities, the models were interpreted with caution. Additionally, a note was added to the results to indicate that these models should not be generalized to the larger population without future replication in more robust samples.

In CTs, a confusion matrix is used to display the number of correctly and incorrectly classified cases in a final CTs based on the parsimonious model parameters that were established through the prediction error, cross-validation error, and standard error. Each confusion matrix contains four values: true positives (the number of cases in the CT that endorsed attempting suicide multiple attempts and was correctly classified as such), false positives (cases that did not

endorse multiple suicide attempts and was incorrected classified as such based on the CT parameters), true negatives (cases that did not endorse multiple suicide attempts and was correctly classified as such), and false negatives (cases that endorsed multiple suicide attempts and was incorrectly classified as not attempting suicide multiple times based on the CT parameters; Gupta, 2015). Based on the values in the confusion matrix, three parameters can be calculated to evaluate the effectiveness of the CT: accuracy, sensitivity, and specificity.

Accuracy in CT is the percentage of accurately classified cases (true positives and true negatives) divided by the total number of cases (true positives, false positives, true negatives, false negatives) and then multiplied by 100 (Gupta, 2015). Sensitivity is defined as the percentage of participants who were accurately identified in the CT as engaging in the outcome variable—attempting suicide multiple times in the present study. Sensitivity is calculated by dividing the number of true positives by the sum of true positives and false negatives (Lalkhen & McCluskey, 2008). Specificity, on the other hand, is defined as the percentage of participants who were accurately identified as not engaging in the outcome variable, attempting suicide once in the present study. Specificity is calculated by dividing the number of true negatives by the sum of true negatives and false positives (Lalkhen & McCluskey, 2008). The "gold standard" of a CT is have sensitivity and specificity exceeding 95% because this combination would produce the most accurate CT (greater than 95%; Swift et al., 2022). Often, increases in sensitivity cause decreases in specificity, and vice versa, creating a trade off when reaching an acceptable accuracy percentage; similarly, imbalanced datasets and rare outcomes can influence these statistics (Gallagher, 2003). Therefore, specificity, sensitivity, and accuracy of 80% or high is considered good (Bertsimas & Dunn, 2017). Given that the present study was exploratory and

used imbalanced datasets when comparing multiple suicide attempts to never attempting suicide, CTs with sensitivity, specificity, and accuracy below 80% were interpreted with caution.

Because CTs tend to be dominated by proximal predictors, the CTs in the present study were run three times, once with proximal predictors only, once with distal predictors only, and once with all proximal and distal predictors. Although previous researchers have utilized machine learning techniques to identify correlates of self-injurious thoughts and behaviors (see Burke et al., 2019; Burke et al., 2020; Wallace et al., 2020), the present approach is the first to predict multiple suicide attempts among a cohort sequential dataset of Colorado adolescents and assess if these finding differ for individuals who identify with expansive gender identities and sexual orientations when examining all proximal and distal predictors of suicide.

**Data Management**

The Healthy Kids Colorado Survey (CDPHE, 2020), due to its size and modular design, has both planned missingness and incidental missingness. These two types of missingness complicated interpretations in the machine learning analyses because the two types of missingness both appeared as empty cells within the datasets. To differentiate between planned and incidental missingness in the model outputs, the present study replaced all planned missingness cells with "0" and retained all incidental missingness as blank or *NA* cells. With the planned missingness differentiated, the classification trees managed missing data through surrogate splits. A surrogate split in classification trees is used when a primary variable in a classification tree has missing values but another variable in the dataset that is unrelated to the primary variable performs similarly to that primary variable (both variables send 5.5 observations to the left for every 1 observation to the right). The unrelated variable is then used as a surrogate or in place of the primary variable on the missing values. If the first surrogate

variable also has missing values, another surrogate variable that is unrelated to the first surrogate variable is used to account for the missing values in the first surrogate variable. The effectiveness of each surrogate variable is determined by how similarly the surrogate variable performs compared to the primary variable (measured through the *agree* term), how much the surrogate value decreases the impurity of the node caused by the missing data, and the number of missing splits in the primary node that are accounted for by the surrogate split (Therneau & Atkinson, 1997). Given the sample size for each year of data collection analyzed in the present study, it was anticipated that data would be missing on every primary variable; therefore, surrogate splits were expected and appeared in every classification tree.

In order to best address the first and second research questions of the present study, the dataset for each year of data collection was split into two smaller datasets based on dichotomous options of the outcome variable. One dataset compared individuals who attempted suicide multiple times to individuals who attempted once, and the second dataset compared individuals who attempted suicide multiple times to those who never attempted suicide. To address the third research question, the original datasets were split to only include participants who identified with one or more of the following identities (labeled expansive gender identity and sexual orientation in the present study): transgender identity, unknown gender identity, gay or lesbian, bisexual, unknown sexual orientation. Once the dataset was reduced to only include participants who identified as having an expansive gender identity or sexual orientation, the dataset was then further split so that comparisons could be drawn across participants who attempt suicide multiple times compared to those who attempt suicide once and those who never attempt suicide.

To conduct the machine learning analyses, the each of the datasets described earlier were split into two parts before statistical analyses were conducted and after the planned missingness

was addressed. The first part consisted of 70% of the original dataset and was considered the training set that was used to optimize the stopping rules of the CT analyses until a parsimonious tree was reached for that explained the outcome variable. The second part of the dataset, which was the remaining 30% of the dataset, was considered the testing set because it tested the accuracy at predicting the outcome variable using the stopping rules established in the training set. Because the present study evaluated rare outcome data, all training and testing datasets were stratified on the outcome variable to ensure that incidents of the outcome variable were evenly distributed across the splits. See Tables 2, 3, and 4 for a breakdown of the outcome and demographic variables across each of the training and testing datasets utilized in the present study.

**Table 2**

*2015 Training and Testing Dataset Outcome Variable Proportions*

| **Dataset** | *Whole Dataset N (%)* | *Training Multi vs. Never N (%)* | *Testing Multi vs. Never N (%)* | *Training Expansive Identities N (%)* | *Testing Expansive Identities N (%)* | *Training Multi vs. Single N (%)* | *Testing Multi vs. Single N (%)* |
|---|---|---|---|---|---|---|---|
| Never Attempted | 12,813 (91.27) | 9,618 (95.55) | 3,195 (95.20) | 1,258 (85.58) | 420 (85.54) | -- | -- |
| Single Attempt | 617 (4.39) | -- | -- | -- | -- | 462 (50.33) | 155 (50.32) |
| Multiple Attempts | 609 (4.34) | 448 (4.45) | 161 (4.80) | 212 (14.42) | 71 (14.46) | 456 (49.67) | 153 (49.68) |
| Age | *M* = 15.68 (*SD* = 1.22) | *M* = 15.65 (*SD* = 1.21) | *M* = 15.65 (*SD* = 1.22) | *M* = 15.55 (*SD* = 1.29) | *M* = 15.52 (*SD* = 1.25) | *M* = 15.55 (*SD* = 1.24) | *M* = 15.52 (*SD* = 1.31) |
| Female | 7,987 (50.61) | 5,072 (50.88) | 1,675 (50.35) | 877 (61.41) | 317 (65.50) | 623 (69.22) | 214 (71.10) |
| Male | 7,794 (49.39) | 4,896 (49.12) | 1,652 (49.65) | 551 (38.59) | 167 (34.50) | 277 (30.78) | 87 (28.90) |
| Not Transgender | 14,236 (93.49) | 9,245 (93.26) | 3,097 (93.40) | -- | -- | 767 (84.75) | 252 (83.44) |
| Transgender | 372 (2.44) | 211 (21.29) | 58 (17.49) | -- | -- | 76 (8.40) | 25 (8.29) |
| Unsure of Transgender Identity | 233 (1.53) | 135 (1.36) | 52 (1.57) | -- | -- | 30 (3.31) | 8 (2.65) |
| Do Not Understand the Question | 387 (2.54) | 212 (2.14) | 74 (2.23) | -- | -- | 26 (2.87) | 10 (3.31) |
| White | 11,483 (76.18) | 7,501 (77.59) | 2,507 (78.81) | 1,039 (68.45) | 354 (70.24) | 634 (66.53) | 220 (70.06) |
| American Indian or Alaskan Native | 1,439 (9.55) | 888 (9.19) | 286 (8.99) | 162 (10.67) | 65 (12.90) | 127 (13.33) | 45 (14.33) |
| Black or African American | 1,092 (7.24) | 637 (6.59) | 194 (6.10) | 145 (9.55) | 42 (8.33) | 83 (8.71) | 25 (7.96) |
| Asian | 700 (4.64) | 433 (4.48) | 149 (4.68) | 121 (7.97) | 27 (5.35) | 69 (7.24) | 14 (4.46) |
| Native Hawaiian or Other Pacific Islander | 359 (2.38) | 208 (2.15) | 55 (1.73) | 51 (3.36) | 16 (3.17) | 40 (4.20) | 10 (3.18) |
| Not Hispanic/Latinx | 10,296 (65.96) | 6,747 (68.42) | 2,233 (67.81) | 951 (65.72) | 313 (64.54) | 543 (60.07) | 182 (60.47) |
| Hispanic/Latinx | 5,314 (34.04) | 3,114 (31.58) | 1,060 (32.19) | 496 (34.28) | 172 (35.46) | 361 (39.93) | 119 (39.53) |
| Heterosexual | 13,269 (86.67) | 8,650 (87.08) | 2,868 (86.36) | -- | -- | 570 (62.98) | 181 (59.54) |
| Bisexual | 1,049 (6.85) | 603 (6.07) | 214 (6.44) | -- | -- | 213 (23.54) | 79 (25.99) |
| Gay or Lesbian | 290 (1.89) | 162 (1.63) | 68 (2.05) | -- | -- | 52 (5.75) | 17 (5.59) |
| Unsure of Sexual Orientation | 701 (4.58) | 408 (4.11) | 136 (4.10) | -- | -- | 64 (7.07) | 20 (6.58) |

*Note*. Multi vs. Never represents the datasets comparing those who attempted suicide multiple times in the last 12 months to those who never attempted suicide. Multi vs. Single represents the datasets comparing those who attempted suicide multiple times in the last 12 months to those who attempted suicide one time in the last 12 months. Expansive Identities represent the datasets comparing participants with expansive transgender identity and/or sexual orientation who attempting suicide multiple times in the last 12 months to those who never attempted suicide. Due to planned missingness, some of the percentage totals do not add up to 100.

**Table 3**

*2017 Training and Testing Dataset Outcome Variable Proportions*

| Dataset | *Whole Dataset N (%)* | *Training Multi vs. Never N (%)* | *Testing Multi vs. Never N (%)* | *Training Expansive Identities N (%)* | *Testing Expansive Identities N (%)* | *Training Multi vs. Single N (%)* | *Testing Multi vs. Single N (%)* |
|---|---|---|---|---|---|---|---|
| Never Attempted | 41,573 (91.19) | 31,177 (95.47) | 10,396 (95.50) | 4,050 (86.95) | 1,351 (86.94) | -- | -- |
| Single Attempt | 2,044 (4.48) | -- | -- | -- | -- | 1,533 (50.93) | 511 (50.90) |
| Multiple Attempts | 1,979 (3.92) | 1,480 (4.53) | 490 (4.50) | 608 (13.05) | 203 (13.06) | 1,477 (49.07) | 493 (49.10) |
| Age | *M* = 15.62 (*SD* = 1.22) | *M* = 15.63 (*SD* = 1.22) | *M* = 15.63 (*SD* = 1.22) | *M* = 15.63 (*SD* = 1.29) | *M* = 15.62 (*SD* = 1.32) | *M* = 15.52 (*SD* = 1.28) | *M* = 15.48 (*SD* = 1.30) |
| Female | 23,454 (50.19) | 16,191 (49.96) | 5,350 (49.50) | 2,950 (64.85) | 1,008 (66.14) | 1,828 (61.92) | 628 (64.08) |
| Male | 23,273 (49.81) | 16,217 (50.04) | 5,459 (50.50) | 1,599 (35.15) | 516 (33.86) | 1,124 (38.08) | 352 (35.92) |
| Not Transgender | 41,212 (95.33) | 29,004 (89.57) | 9,727 (89.91) | -- | -- | 2,344 (78.74) | 765 (76.88) |
| Transgender | 558 (1.29) | 351 (1.08) | 105 (0.97) | -- | -- | 162 (5.44) | 58 (5.83) |
| Unsure of Transgender Identity | 660 (1.53) | 441 (1.36) | 130 (1.20) | -- | -- | 137 (4.60) | 41 (4.12) |
| Do Not Understand the Question | 835 (1.86) | 566 (1.75) | 170 (1.57) | -- | -- | 82 (2.75) | 38 (3.82) |
| White | 34,259 (75.49) | 24,023 (76.31) | 7,924 (75.88) | 3,313 (69.04) | 1,104 (69.43) | 2,032 (64.04) | 684 (65.08) |
| American Indian or Alaskan Native | 4,094 (9.02) | 2,723 (8.65) | 945 (9.05) | 537 (11.19) | 162 (10.19) | 420 (13.24) | 136 (12.94) |
| Black or African American | 3,136 (6.91 | 2,099 (6.67) | 707 (6.70) | 399 (8.31) | 136 (8.55) | 308 (9.71) | 109 (10.37) |
| Asian | 2,662 (5.87) | 1,822 (5.79) | 604 (5.78) | 367 (7.65) | 133 (8.36) | 258 (8.13) | 75 (7.14) |
| Native Hawaiian or Other Pacific Islander | 1,232 (2.71) | 813 (2.58) | 263 (2.52) | 183 (3.81) | 55 (3.46) | 155 (4.88) | 47 (4.47) |
| Not Hispanic/Latinx | 29,310 (63.20) | 20,598 (63.96) | 6,815 (63.58) | 2,858 (62.61) | 995 (65.55) | 1,695 (57.44) | 533 (54.06) |
| Hispanic/Latinx | 17,069 (36.80) | 11,605 (36.04) | 3,904 (36.42) | 1,707 (37.39) | 523 (34.45) | 1,256 (42.56) | 453 (45.94) |
| Heterosexual | 36,808 (85.34) | 26,088 (80.90) | 8,741 (81.01) | -- | -- | 1,699 (57.34) | 591 (59.46) |
| Bisexual | 3,268 (7.58) | 2,128 (6.60) | 698 (6.47) | -- | -- | 612 (20.65) | 176 (17.71) |
| Gay or Lesbian | 1,038 (2.41) | 671 (2.08) | 212 (1.96) | -- | -- | 169 (5.70) | 51 (5.13) |
| Unsure of Sexual Orientation | 2,018 (4.68) | 1,340 (4.16) | 452 (4.19) | -- | -- | 231 (7.79) | 83 (8.35) |

*Note*. Multi vs. Never represents the datasets comparing those who attempted suicide multiple times in the last 12 months to those who never attempted suicide. Multi vs. Single represents the datasets comparing those who attempted suicide multiple times in the last 12 months to those who attempted suicide one time in the last 12 months. Expansive Identities represent the datasets comparing participants with expansive transgender identity and/or sexual orientation who attempting suicide multiple times in the last 12 months to those who never attempted suicide. Due to planned missingness, some of the percentage totals do not add up to 100.

**Table 4**

*2019 Training and Testing Dataset Outcome Variable Proportions*

| **Dataset** | *Whole Dataset N (%)* | *Training Multi vs. Never N (%)* | *Testing Multi vs. Never N (%)* | *Training Expansive Identities N (%)* | *Testing Expansive Identities N (%)* | *Training Multi vs. Single N (%)* | *Testing Multi vs. Single N (%)* |
|---|---|---|---|---|---|---|---|
| Never Attempted | 41,321 (91.83) | 31,025 (96.01) | 10,296 (95.58) | 4,616 (88.75) | 1,539 (88.75) | -- | -- |
| Single Attempt | 1,908 (4.24) | -- | -- | -- | -- | 1,431 (51.94) | 477 (51.90) |
| Multiple Attempts | 1,766 (3.92) | 1,290 (3.99) | 476 (4.42) | 585 (11.25) | 195 (11.25) | 1,324 (48.06) | 442 (48.10) |
| Age | *M* = 15.69 (*SD* = 1.21) | *M* = 15.70 (*SD* = 1.21) | *M* = 15.68 (*SD* = 1.21) | *M* = 15.70 (*SD* = 1.24) | *M* = 15.68 (*SD* = 1.32) | *M* = 15.59 (*SD* = 1.26) | *M* = 15.60 (*SD* = 1.31) |
| Female | 22,831 (49.93) | 15,844 (49.80) | 5,199 (48.99) | 3,359 (66.48) | 1,081 (64.42) | 1,642 (61.15) | 561 (63.18) |
| Male | 22,898 (50.07) | 15,973 (50.20) | 5,414 (51.01) | 1,694 (33.52) | 597 (35.58) | 1,043 (38.85) | 327 (36.82) |
| Not Transgender | 42,688 (95.33) | 30,007 (95.78) | 9,972 (95.68) | -- | -- | 2,268 (86.17) | 754 (85.20) |
| Transgender | 587 (1.31) | 355 (1.13) | 135 (1.30) | -- | -- | 139 (5.28) | 51 (5.76) |
| Unsure of Transgender Identity | 667 (1.49) | 414 (1.32) | 143 (1.37) | -- | -- | 128 (4.86) | 45 (5.08) |
| Do Not Understand the Question | 835 (1.86) | 554 (1.77) | 172 (1.65) | -- | -- | 97 (3.69) | 35 (3.95) |
| White | 34,040 (75.21) | 23,924 (76.10) | 7,932 (75.09) | 3,828 (70.07) | 1,247 (67.51) | 1,873 (64.39) | 619 (64.41) |
| American Indian or Alaskan Native | 4,051 (8.95) | 2,675 (8.51) | 1,001 (9.48) | 562 (10.29) | 200 (10.83) | 396 (13.61) | 138 (14.36) |
| Black or African American | 3,432 (7.58) | 2,282 (7.26) | 805 (7.62) | 475 (8.69) | 177 (9.58) | 299 (10.28) | 99 (10.30) |
| Asian | 2,576 (5.69) | 1,778 (5.57) | 580 (5.49) | 392 (7.18) | 153 (8.28) | 197 (6.77) | 64 (6.66) |
| Native Hawaiian or Other Pacific Islander | 1,158 (2.56) | 780 (2.48) | 245 (2.31) | 206 (3.77) | 70 (3.79) | 144 (4.95) | 41 (4.27) |
| Not Hispanic/Latinx | 29,762 (65.58) | 20,856 (66.01) | 6,987 (66.17) | 3,363 (66.34) | 1,121 (67.13) | 1,558 (57.94) | 523 (57.98) |
| Hispanic/Latinx | 15,620 (34.42) | 10,739 (33.99) | 3,572 (33.83) | 1,706 (33.66) | 549 (32.87) | 1,131 (42.06) | 379 (42.02) |
| Heterosexual | 37,502 (83.89) | 26,496 (84.87) | 8,839 (84.98) | -- | -- | 1,654 (62.70) | 525 (59.59) |
| Bisexual | 3,957 (8.85) | 2,558 (8.19) | 845 (8.12) | -- | -- | 630 (23.88) | 225 (25.54) |
| Gay or Lesbian | 1,127 (2.52) | 736 (2.36) | 254 (2.44) | -- | -- | 168 (6.37) | 64 (7.26) |
| Unsure of Sexual Orientation | 2,120 (4.74) | 1,429 (4.58) | 463 (4.45) | -- | -- | 186 (7.05) | 67 (7.60) |

*Note*. Multi vs. Never represents the datasets comparing those who attempted suicide multiple times in the last 12 months to those who never attempted suicide. Multi vs. Single represents the datasets comparing those who attempted suicide multiple times in the last 12 months to those who attempted suicide one time in the last 12 months. Expansive Identities represent the datasets comparing participants with expansive transgender identity and/or sexual orientation who attempting suicide multiple times in the last 12 months to those who never attempted suicide. Due to planned missingness, some of the percentage totals do not add up to 100.

# Chapter 3 - Results

In total, 24 classification trees (CTs) were run investigating 36 variables across the 2015, 2017, and 2019 datasets. There were eight CTs for each year of data collection. Each CT was categorized into four predictor subsets (all predictors, proximal predictors only, and distal predictors only for all participants and all predictors for individuals who identify as having one or more expansive gender identity and/or sexual orientation) and two comparison subsets (multiple suicide attempts compared to one suicide attempt and multiple suicide attempts compared to no suicide attempts). Out of the 24 trees that were attempted, 20 were successful in identifying predictors of multiple suicide attempts, and 26 predictors were used to form these trees.

## Multiple Suicide Attempts Compared to Single Suicide Attempts

Across the 12 classification trees that analyzed the predictors of multiple suicide attempts compared to single suicide attempts, 10 were able to identify predictors for multiple suicide attempts. Two trees demonstrated an immediate increase in the cross-validation error, indicating the trees could only be formed if they were immediately overfit to the data. See Table 5 for a summary of all classification tree parameters that were used to interpret these trees.

### *All Predictors for All Participants*

After pruning the 2015 tree exploring all predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 1 was identified as the best model for the data. The prediction error for this tree was 0.73, indicating the tree explained 27% of the variance in this sample. The cross-validation error was 0.82 (95% C.I. = 0.79 - 0.85), meaning that, on average, the tree explained 18% of the variance across cross validation samples,

**Table 5**

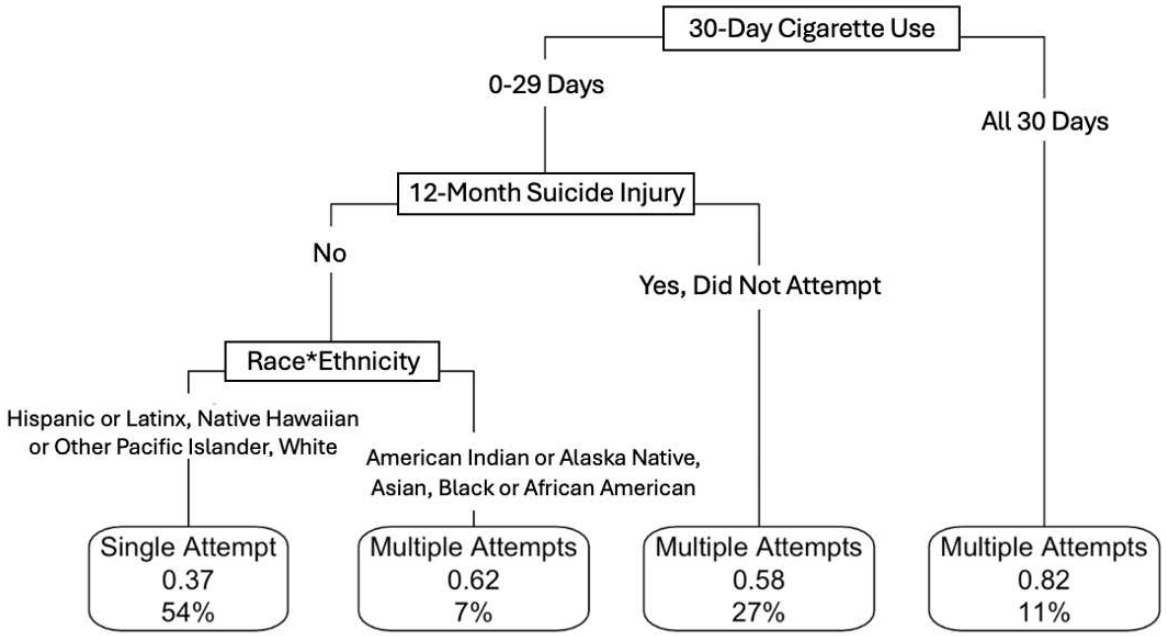
*Classification Tree Parameters Comparing Multiple Suicide Attempts to Single Suicide Attempts in the Last 12 Months*

| **Dataset** | *Prediction Error* | *Cross Validation Error* | *Confidence Intervals* | *Accuracy %* | *Sensitivity %* | *Specificity %* | *n* |
|---|---|---|---|---|---|---|---|
| All Variables | | | | | | | |
| 2015 | 0.73 | 0.82 | 0.79 - 0.85 | 63.6 | 63.5 | 63.8 | 918 |
| 2017 | 0.78 | 0.84 | 0.82 – 0.86 | 58.7 | 57.9 | 59.8 | 3010 |
| 2019 | 0.81 | 0.96 | 0.94 – 0.98 | 59.3 | 57.5 | 64.8 | 2755 |
| Expansive Transgender Identity and/or Sexual Orientation | | | | | | | |
| 2015 | -- | -- | -- | -- | -- | -- | -- |
| 2017 | -- | -- | -- | -- | -- | -- | -- |
| 2019 | 0.87 | 0.89 | 0.86 - 0.92 | 57.7 | 67.4 | 56.3 | 1096 |
| Proximal Variables Only | | | | | | | |
| 2015 | 0.85 | 0.85 | 0.82 - 0.88 | 60.1 | 56.3 | 90.0 | 918 |
| 2017 | 0.82 | 0.84 | 0.82 - 0.86 | 56.9 | 55.1 | 62.4 | 3009 |
| 2019 | 0.82 | 0.88 | 0.86 - 0.90 | 58.5 | 56.8 | 64.2 | 2763 |
| Distal Variables Only | | | | | | | |
| 2015 | 0.71 | 0.80 | 0.77 - 0.83 | 60.7 | 59.2 | 62.9 | 918 |
| 2017 | 0.84 | 0.92 | 0.90 - 0.94 | 59.6 | 58.2 | 61.9 | 3010 |
| 2019 | 0.83 | 0.93 | 0.91 - 0.95 | 59.4 | 60.1 | 58.5 | 2755 |

*Note*. The classification trees exploring all variables for participants with an expansive transgender identity and/or sexual orientation in the 2015 and 2017 Health Kids Colorado Survey datasets were not interpreted due to immediate increases in the cross-validation error.

**Figure 1**

*Final Classification Tree for All Predictors and All Participants in 2015 Predicting Multiple and Single Suicide Attempts*




*Note*. Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and all predictors in the 2015 Healthy Kids Colorado Survey. Prediction standard error = 0.73, cross-validated standard error = 0.82. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 918 participants.

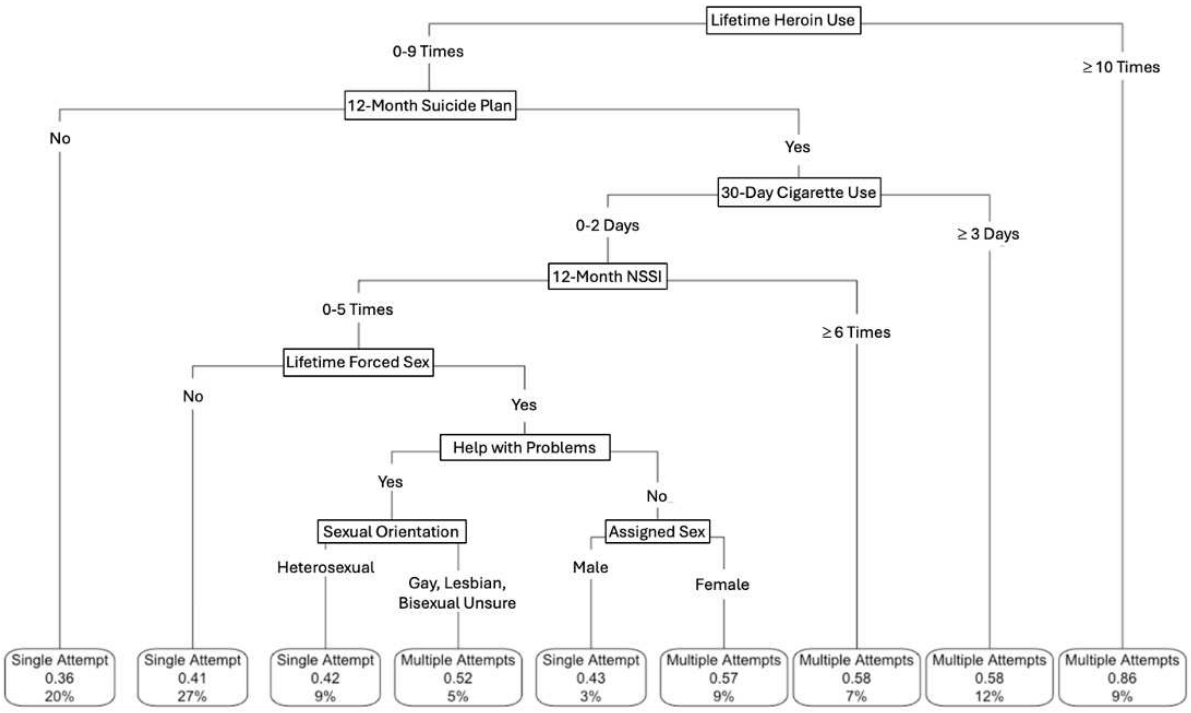
and variance explained could range from 15% to 21%. The accuracy rating of this tree was 63.6%. The final tree contained four subsamples, three that were indicated by multiple suicide attempts and one that indicated single suicide attempts. Three predictors were utilized to create these subsamples: the number of days in the last 30 days when participants smoked cigarettes, if the participants had to be treated by a nurse or doctor for injuries sustained during a suicide attempt in the last 12 months, and an intersection variable of participant race and ethnicity. The three groups predicted to attempt suicide multiple times were (1) individuals who smoked

cigarettes on all 30 days in the last month, (2) individuals who smoked cigarettes on fewer than 30 days in the last month and either sustained an injury during a
suicide attempt that required medical treatment in the last 12 months or they did not attempt suicide in the last 12 months, and (3) individuals who smoked cigarettes on fewer than 30 days in last month, did not suffer an injury during a suicide attempt in the last 12 months that required medical attention, and identified as American Indian or Alaska Native, Asian, and Black or African American. The one group predicted to attempt suicide one time included individuals who smoked cigarettes on fewer than 30 days in the last month, did not suffer an injury during a suicide attempt in the last 12 months that required medical attention, and identified as Hispanic or Latino, Native Hawaiian or Pacific Islander, or White.

After pruning the 2017 tree exploring all predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 2 was identified as the best model for the data. The prediction error for this tree was 0.78, indicating the tree explained 12% of the variance in this sample. The cross-validation error was 0.84 (95% C.I. = 0.82 – 0.86, meaning the tree was estimated to explain, on average, 16% of the variance across cross validation samples, and that variance explained could range from 14% to 18%. The accuracy rating of this tree was 58.7%. The final tree consisted of nine subsamples, five that indicated multiple suicide attempts and four that indicated single suicide attempts. Eight predictors were utilized to create these subsamples: ever using heroin during one's life, creating a plan for suicide in the last 12 months, the number of days in the last 30 days when participants smoked cigarettes, the number of times participants engaged in non-suicidal self-injury (NSSI) in the last 12 months, if participants have ever been physically forced to have a sexual encounter they did not want, if the participants know of an adult inside or outside of their school to whom they can

**Figure 2**

*Final Classification Tree for All Predictors and All Participants in 2017 Predicting Multiple and Single Suicide Attempts*




*Note*. Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and all predictors in the 2017 Healthy Kids Colorado Survey. Prediction standard error = 0.78, cross-validated standard error = 0.84. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 3,010 participants.

talk if they are having a problem, participant sexual orientation, and participant sex assigned at birth. The five groups predicted to attempt suicide multiple times were (1) individuals who used heroin 10 or more times in their lifetime; (2) individuals who used heroin 9 or fewer times in their lifetime, created a plan for suicide in the last 12 months, and smoked cigarettes on at least 3 days in the last month; (3) individuals who used heroin 9 or fewer times in their lifetime, created a plan for suicide in the last 12 months, smoked cigarettes on 2 or fewer days in the last month, and engaged in NSSI six or more times in the last 12 months; (4) individuals who used heroin 9

or fewer times in their lifetime, created a plan for suicide in the last 12 months, smoked cigarettes on 2 or fewer days in the last month, engaged in NSSI 5 or fewer times in the last 12 months, were physically forced into a sexual encounter in their lifetime, did not identify an adult to whom they could talk if they were having a problem, and identified as female; and (5) individuals who used heroin 9 or fewer times in their lifetime, created a plan for suicide in the last 12 months, smoked cigarettes on 2 or fewer days in the last month, engaged in NSSI 5 or fewer times in the last 12 months, were physically forced into a sexual encounter in their lifetime, identified an adult to whom they could talk if they were having a problem, and identified as bisexual, gay or lesbian, or unsure of their sexual orientation.

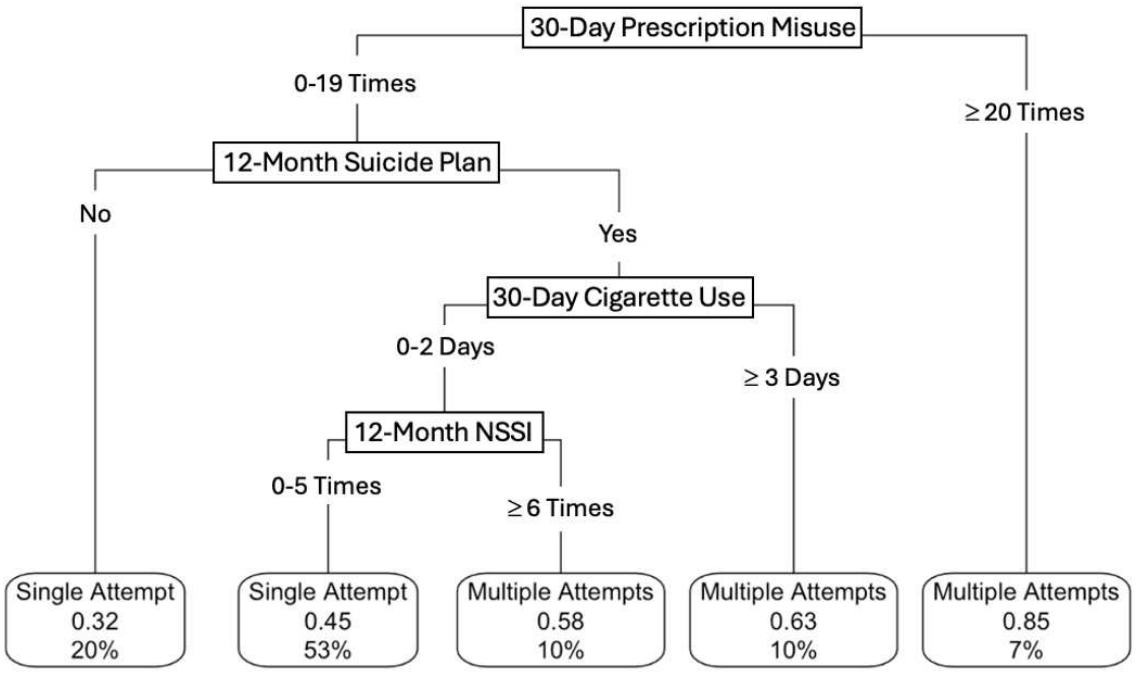
The four groups predicted to attempt suicide one time included (1) individuals who used heroin 9 or fewer times in their lifetime and did not plan for suicide in the last 12 months; (2) individuals who used heroin 9 or fewer times in their lifetime, created a plan for suicide in the last 12 months, smoked cigarettes on 2 or fewer days in the last month, engaged in NSSI 5 or fewer times in the last 12 months, and were not physically forced into a sexual encounter they did not want in their lifetime; (3) individuals who used heroin 9 or fewer times in their lifetime, created a plan for suicide in the last 12 months, smoked cigarettes on 2 or fewer days in the last month, engaged in NSSI 5 or fewer times in the last 12 months, and were physically forced into a sexual encounter they did not want in their lifetime, identified an adult to whom they could talk if they were having a problem, and identified as heterosexual; (4) individuals who used heroin 9 or fewer times in their lifetime, created a plan for suicide in the last 12 months, smoked cigarettes on 2 or fewer days in the last month, engaged in NSSI 5 or fewer times in the last 12 months, and were physically forced into a sexual encounter they did not want in their lifetime,

did not identify an adult to whom they could talk if they were having a problem, and identified as male.

After pruning the 2019 tree exploring all predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 3 was identified as the best

**Figure 3**

*Final Classification Tree for All Predictors and All Participants in 2019 Predicting Multiple and Single Suicide Attempts*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and all predictors in the 2019 Healthy Kids Colorado Survey. Prediction standard error = 0.82, cross-validated standard error = 0.96. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 2,755 participants.

model for the data. The prediction error for this tree was 0.81, indicating the tree explained 19% of the variance in this sample. The cross-validation error was 0.96 (95% C.I. = 0.94 – 0.98), meaning that, on average, the tree explained 4% of the variance across cross validation samples,

and that variance explained could range from 2% to 6%. The accuracy rating of this tree was 59.3%. The final tree consisted of five subsamples, three that predicted multiple suicide attempts and two that predicted single suicide attempts. Four predictors were utilized to create these subsamples: the number of times participants took prescription pain medication without a prescription or different from a doctor's use plan in the last month (herein referred to as misusing prescription pain medication in the last month), if the participants created a plan for suicide in the last 12 months, the number of days in the last month when participants smoked cigarettes, and the number of times participants engaged in NSSI in the last 12 months. The three groups predicted to attempt suicide multiple times were (1) individuals who misused prescription pain medication at least 20 times in the last month, (2) individuals who misused prescription pain medication 19 or fewer times in the last month (including never misusing prescription pain medication in the last month), created a plan for suicide in the last 12 months, and smoked cigarettes on at least three or more days in the last month; and (3) individuals who misused prescription pain medication 19 or fewer times in the last month (including never misusing prescription pain medication in the last month), created a plan for suicide in the last 12 months, smoked cigarettes on two or fewer days in the last month, and engaged in NSSI six or more times in the last 12 months. The two groups predicted to attempt suicide one time included (1) individuals who misused prescription pain medication 19 or fewer times in the last month (including never misusing prescription pain medication in the last month) and did not create a plan for suicide in the last 12 months, and (2) individuals who misused prescription pain medication 19 or fewer times in the last month (including never misusing prescription pain medication in the last month), created a plan for suicide in the last 12 months, smoked cigarettes

on two or fewer days in the last month, and engaged in NSSI five or fewer times in the last 12 months.

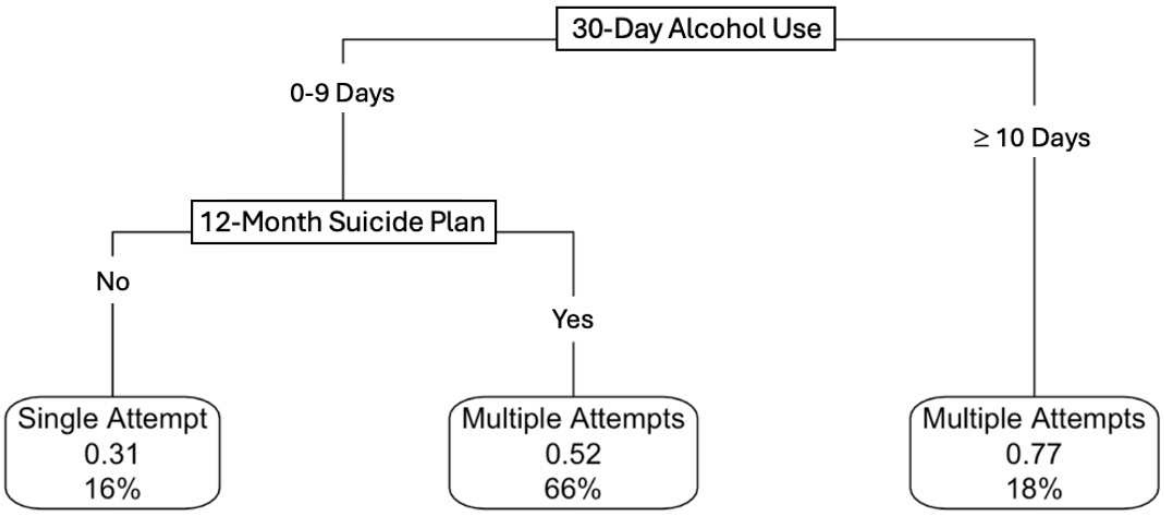
### *All Predictors for Participants with Expansive Gender Identity and/or Sexual Orientation*

Two of the three trees exploring all predictors of multiple suicide attempts compared to single suicide attempts for participants who identified with expansive gender identity and/or sexual orientation demonstrated immediate increases in the cross-validation error, indicating the trees were overfitting and could not be interpreted accurately. Therefore, the tree for the 2019 dataset is the only one that can be interpreted in this subset. The pruned tree exploring all predictors of multiple suicide attempts compared to single suicide attempts for individuals with expansive gender identity or sexual orientation is presented in Figure 4.

The prediction error for this tree was 0.87, indicating the tree explained 13% of the variance in this sample. The cross-validation error was 0.89 (95% C.I. = 0.86 - 0.92), meaning that on average the tree explained 11% of the variance across cross validation samples, and that variance explained could range from 8% to 14%. The accuracy rating of this tree was 57.7%. The final tree consisted of three subsamples, two that indicated multiple suicide attempts and one that indicated single suicide attempts. Two predictors were utilized to create these subsamples: the number of days in the last months when participants drank alcohol and if the participants created a plan for suicide in the last 12 months. The two groups predicted to attempt suicide multiple times were (1) individuals drank alcohol on 10 or more days in the last month, and (2) individuals who drank alcohol on 9 or fewer days in the last month and made a plan for suicide in the last 12 months. The one group predicted to attempt suicide one time included individuals who drank alcohol on 9 or fewer days in the last month and did not make a plan for suicide in the last 12 months.

**Figure 4**

*Final Classification Tree for All Predictors and Participants who Identified with an Expansive Gender Identity or Sexual Orientation in 2019 Predicting Multiple and Single Suicide Attempts*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all predictors and only participants who identified with an expansive gender identity or sexual orientation in the 2019 Healthy Kids Colorado Survey. Prediction standard error = 0.87, cross-validated standard error = 0.89. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 1,096 participants.

### *Proximal Predictors Only*

After pruning the 2015 tree exploring only the proximal predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 5 was identified as the best model for the data. The prediction error for this tree was 0.85, indicating the tree explained 15% of the variance in this sample. The cross-validation error was 0.85 (95% C.I. = 0.82 - 0.88), meaning that, on average, the tree explained 15% of the variance across cross validation samples, and that variance explained could range from 12% to 18%. The accuracy rating of this tree was 60.1%. The final tree consisted of two subsamples, one that predicted multiple suicide attempts

**Figure 5**

*Final Classification Tree for All Participants and Proximal Predictors Only in 2015 Predicting Multiple and Single Suicide Attempts*

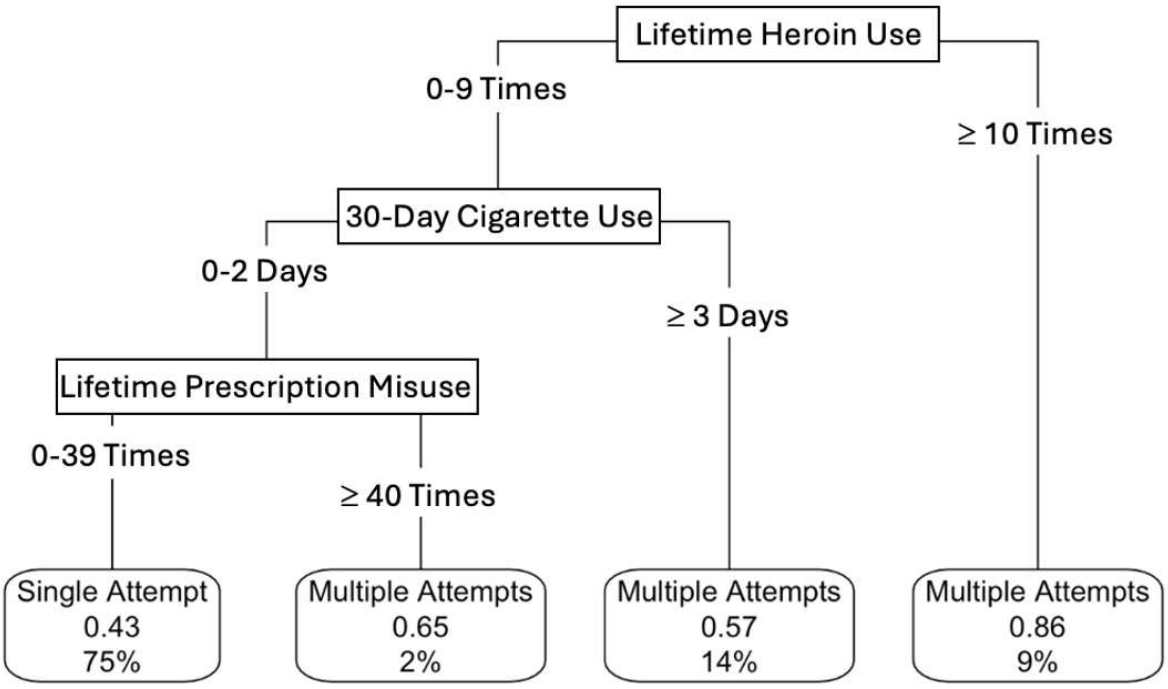

*Note.* Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and only proximal predictors in the 2015 Healthy Kids Colorado Survey. Prediction standard error = 0.85, cross-validated standard error = 0.85. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 918 participants.

and one that predicted single suicide attempts. One predictor was utilized to create these subsamples: the number of days in the last 30 days when participants smoked cigarettes. The one group predicted to attempt suicide multiple times was individuals who smoked cigarettes on all 30 days in the last month. The one group predicted to attempt suicide one time included individuals who smokes cigarettes on fewer than 30 days in the last month.

After pruning the 2017 tree exploring only the proximal predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 6 was identified as the best model for the data. The prediction error for this tree was 0.82, indicating the tree explained 18% of the variance in this sample. The cross-validation error was 0.84 (95% C.I. = 0.82 - 0.86),

**Figure 6**

*Final Classification Tree for All Participants and Proximal Predictors Only in 2017 Predicting Multiple and Single Suicide Attempts*




*Note*. Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and only proximal predictors in the 2017 Healthy Kids Colorado Survey. Prediction standard error = 0.82, cross-validated standard error = 0.84. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 3,009 participants.

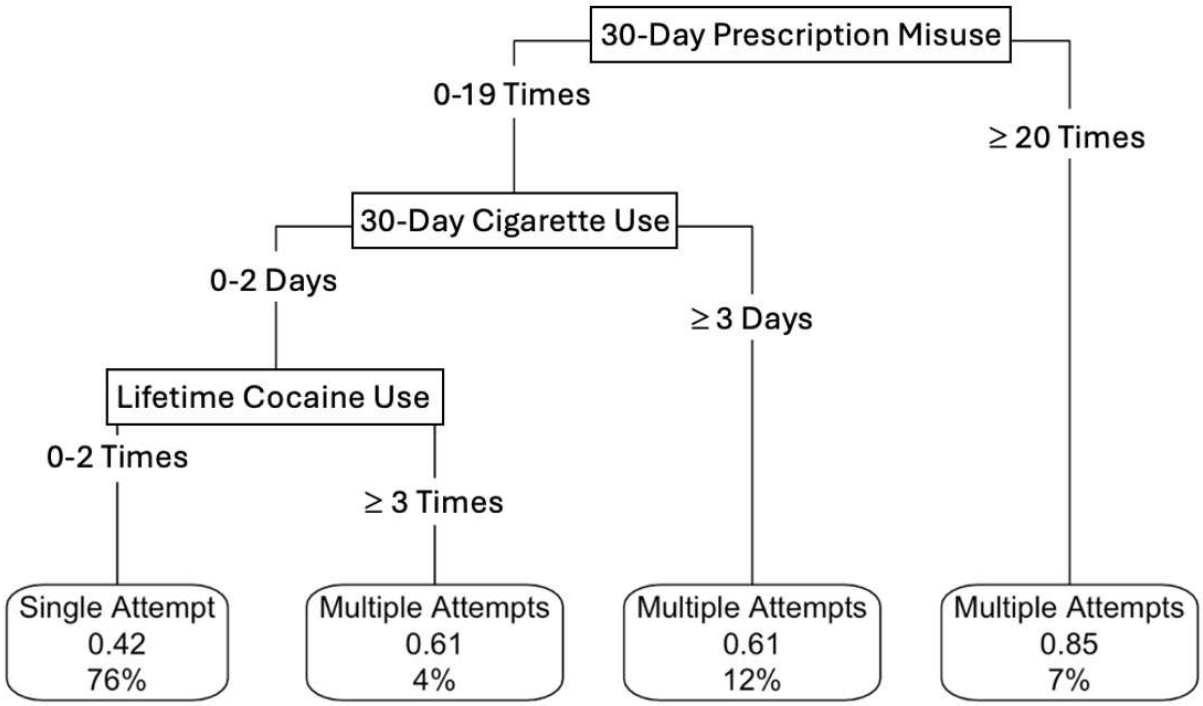
meaning that, on average, the tree explained 16% of the variance across cross validation samples, and that variance explained could range from 14% to 18%. The accuracy rating of this tree was 56.9%. The final tree consisted of four subsamples, three that indicated multiple suicide attempts and one that indicated single suicide attempts. Three predictors were utilized to create these subsamples: the number of times individuals endorsed using heroin in their lifetime, the number of days in the last 30 days when participants smoked cigarettes, and the number of times individuals misused prescription medications in their lifetime. The three groups predicted to

attempt suicide multiple times were (1) individuals who used heroin 10 or more times in their lifetime, (2) individuals who used heroin nine or fewer times in their lifetime and smoked cigarettes on three or more days in the last 30 days, and (3) individuals who used heroin nine or fewer times in their lifetime, smoked cigarettes on two or fewer days in the last 30 days, and misused prescription medications 40 or more times in their lifetime. The one group predicted to attempt suicide one time included individuals who used heroin nine or fewer times in their lifetime, smoked cigarettes on two or fewer days in the last 30 days, and misused prescription medications 39 or fewer times in their lifetime.

After pruning the 2019 tree exploring only the proximal predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 7 was identified as the best model for the data. The prediction error for this tree was 0.82, indicating the tree explained 18% of the variance in this sample. The cross-validation error was 0.88 (95% C.I. = 0.86 - 0.90), meaning that, on average, the tree explained 12% of the variance across cross validation samples, and that variance explained could range from 10% to 14%. The accuracy rating of this tree was 58.5%. The final tree consisted of four subsamples, three that predicted multiple suicide attempts and one that predicted single suicide attempts. Three predictors were utilized to create these subsamples: the number of days in the last month when participants misused prescription medications, the number of days in the last month when participants smoked cigarettes, and the number of times they have ever used cocaine in their lifetime. The three groups predicted to attempt suicide multiple times were (1) individuals who misused prescription medications 20 or more times in the last month; (2) individuals who misused prescription medications 19 or fewer times in the last month and smoked cigarettes on three or more days in the last month; and (3) individuals who misused prescription medications 19 or fewer times in the last month, smoked

**Figure 7**

*Final Classification Tree for All Participants and Proximal Predictors Only in 2019 Predicting Multiple and Single Suicide Attempts*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and only proximal predictors in the 2019 Healthy Kids Colorado Survey. Prediction standard error = 0.82, cross-validated standard error = 0.88. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 2,753 participants.

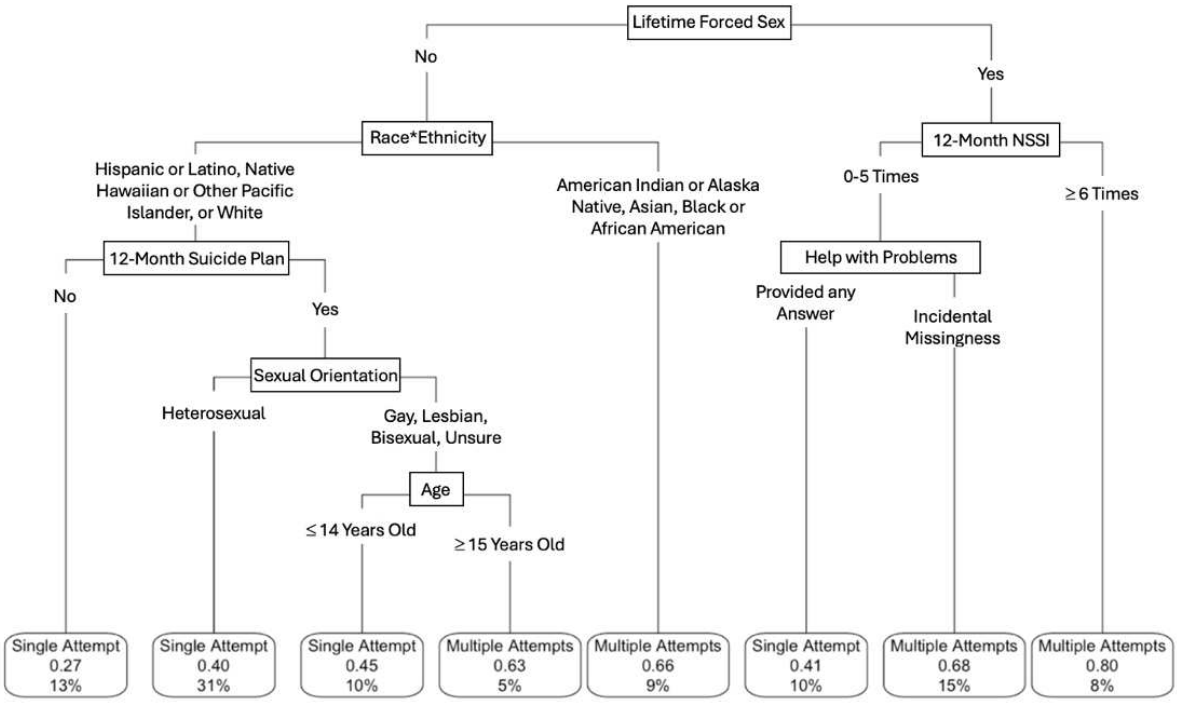
cigarettes on two or fewer days in the last month, and used cocaine three or more times in their lifetime. The one group predicted to attempt suicide one time included individuals who misused prescription medications 19 or fewer times in the last month, smoked on two or fewer days in the last month, and used cocaine two or fewer times in their lifetime.

***Distal Predictors Only***

After pruning the 2015 tree exploring only distal predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 8 was identified as the best

**Figure 8**

*Final Classification Tree for All Participants and Distal Predictors Only in 2015 Predicting Multiple and Single Suicide Attempts*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and only distal predictors in the 2015 Healthy Kids Colorado Survey. Prediction standard error = 0.71, cross-validated standard error = 0.80. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 918 participants.

model for the data. The prediction error for this tree was 0.71, indicating the tree explained 29% of the variance in this sample. The cross-validation error was 0.80 (95% C.I. = 0.77 - 0.83), meaning that, on average, the tree explained 20% of the variance across cross validation samples, and that variance explained could range from 17% to 23%. The accuracy rating of this tree was 60.7%. The final tree consisted of eight subsamples, four that predicted multiple suicide attempts and four that predicted single suicide attempts. Seven predictors were utilized to create these subsamples: if the participants have ever been physically forced into a sexual encounter they did

not want in their lifetime, an intersection of participant race and ethnicity, if participants created a plan for suicide in the last 12 months, participant sexual orientation, participant age, the number of times participants engaged in NSSI in the last 12 months, and if participants have an adult they can reach out to if they are in a serious problem. The four groups predicted to attempt suicide multiple times were (1) individuals who have been physically forced into a sexual encounter they did not want and engaged in NSSI six or more times in the last 12 months; (2) individuals who have been physically forced into a sexual encounter they did not want, engaged in NSSI five or fewer times in the last 12 months, and did not answer the question about whether they have an adult they can go to if they are in a serious problem; (3) individuals who have not been physically forced into a sexual encounter they did not want and they identify as American Indian or Alaska Native, Asian, or Black or African American; and (4) individuals who have not been physically forced into a sexual encounter they did not want, they identify as Hispanic or Latino, Native Hawaiian or Other Pacific Islander, or White, they developed a plan for suicide in the last 12 months, and they are 15 years old or older.

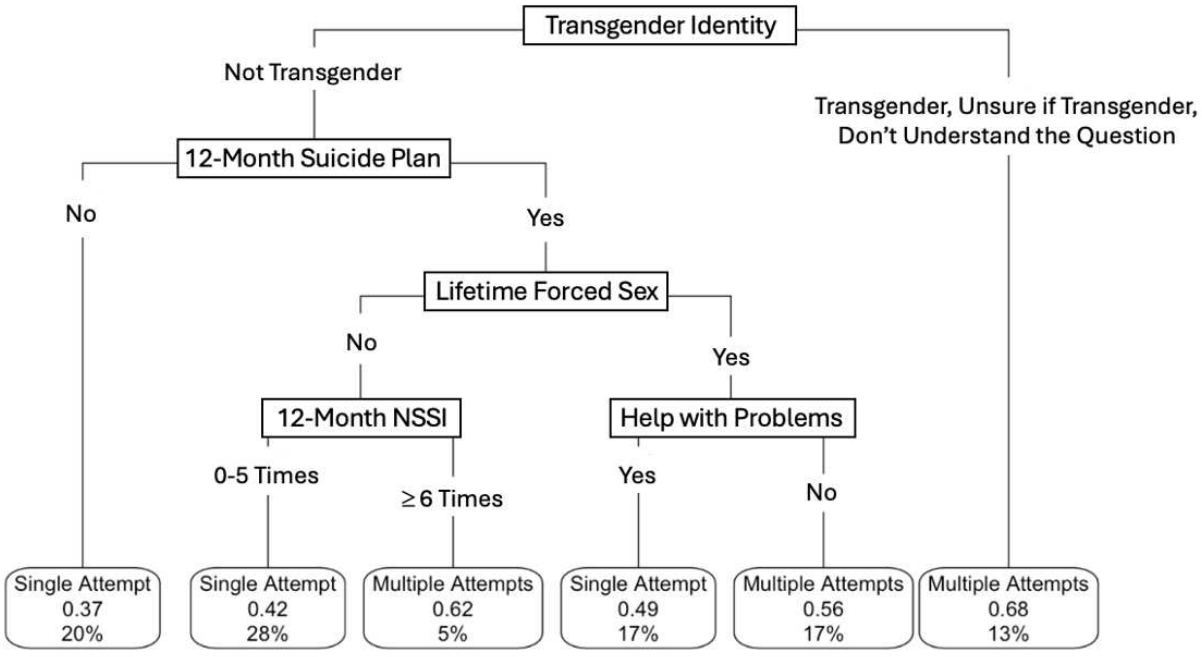
The four groups predicted to attempt suicide one time included (1) individuals who have been physically forced into a sexual encounter they did not want, engaged in NSSI five or fewer times in the last 12 months, and answered the question about whether they have an adult they can go to if they are in a serious problem (any answer provided); (2) individuals who have not been physically forced into a sexual encounter they did not want and they identify as Hispanic or Latino, Native Hawaiian or Other Pacific Islander, or White, and they did not create a plan for suicide in the last 12 months; (3) individuals who have not been physically forced into a sexual encounter they did not want, they identify as Hispanic or Latino, Native Hawaiian or Other Pacific Islander, or White, they did created a plan for suicide in the last 12 months, and they

identify as heterosexual; and (4) individuals who have not been physically forced into a sexual encounter they did not want, they identify as Hispanic or Latino, Native Hawaiian or Other Pacific Islander, or White, they developed a plan for suicide in the last 12 months, they identify as gay or lesbian, bisexual, or unsure of their sexual orientation, and they are 14 years old or younger.

After pruning the 2017 tree exploring only distal predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 9 was identified as the best

**Figure 9**

*Final Classification Tree for All Participants and Distal Predictors Only in 2017 Predicting Multiple and Single Suicide Attempts*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and only distal predictors in the 2017 Healthy Kids Colorado Survey. Prediction standard error = 0.84, cross-validated standard error = 0.92. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 3,010 participants.

model for the data. The prediction error for this tree was 0.84, indicating the tree explained 16%

of the variance in this sample. The cross-validation error was 0.92 (95% C.I. = 0.90 - 0.94), meaning that, on average, the tree explained 8% of the variance across cross validation samples, and that variance explained could range from 6% to 10%. The accuracy rating of this tree was 59.6%. The final tree consisted of six subsamples, three that predicted multiple suicide attempts and three that predicted single suicide attempts. Five predictors were utilized to create these subsamples: participants' transgender identity, if participants created a plan for suicide in the last 12 months, if the participants have ever been physically forced into a sexual encounter they did not want in their lifetime, the number of times participants engaged in NSSI in the last 12 months, and if participants have an adult they can reach out to if they are in a serious problem. The three groups predicted to attempt suicide multiple times were (1) individuals who identified as being transgender, unsure if they are transgender, or they do not understand the question asking about their gender identity; (2) individuals who identified as not being transgender, developed a plan for suicide in the last 12 months, have been physically forced into a sexual encounter they did not want, and did not identify an adult they can go to if they are in a serious problem; and (3) individuals who identified as not being transgender, developed a plan for suicide in the last 12 months, have not been physically forced into a sexual encounter they did not want, and they engaged in self-harm six or more times in the last 12 months.

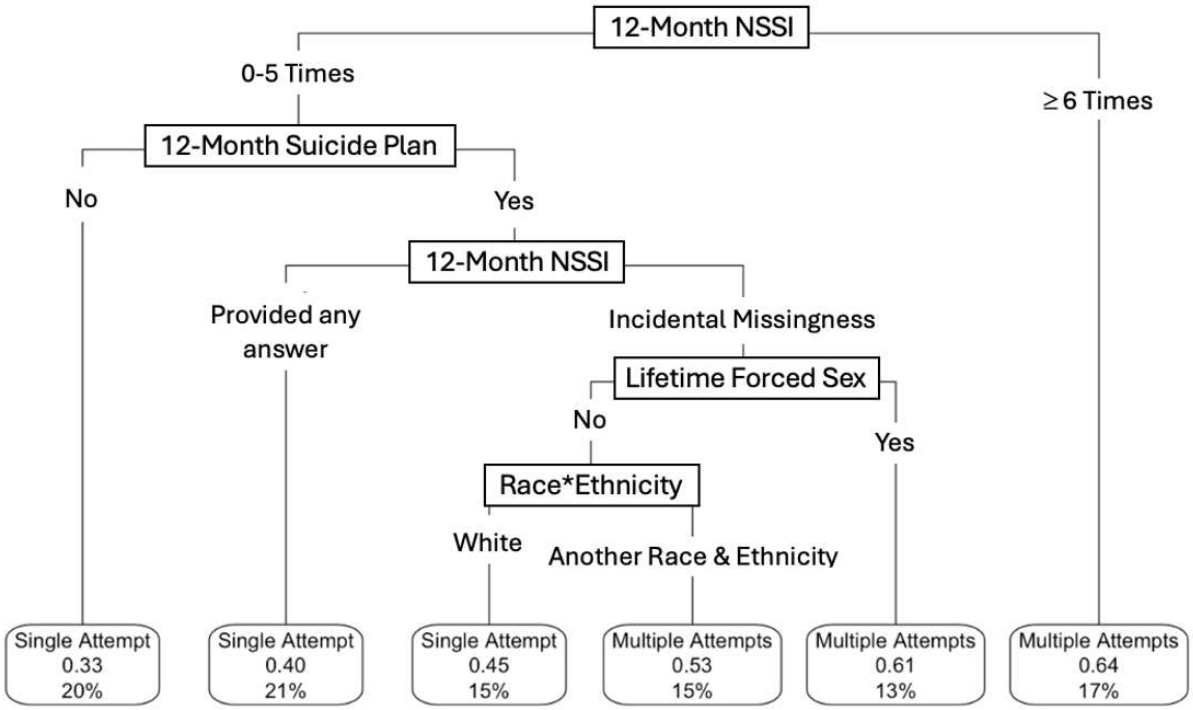
The four groups predicted to attempt suicide one time included (1) individuals who identified as not being transgender and did not develop a plan for suicide in the last 12 months; (2) individuals who identified as not being transgender, created a plan for suicide in the last 12 months, have been physically forced into a sexual encounter they did not want, and identified knowing an adult they can go to if they are in a serious problem; and (3) individuals who identified as not being transgender, developed a plan for suicide in the last 12 months, have been

physically forced into a sexual encounter they did not want, and engaged in NSSI five or fewer times in the last 12 months.

After pruning the 2019 tree exploring only distal predictors of multiple suicide attempts compared to single suicide attempts, the tree presented in Figure 10 was identified as the best

**Figure 10**

*Final Classification Tree for All Participants and Distal Predictors Only in 2019 Predicting Multiple and Single Suicide Attempts*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and single suicide attempts across all participants and only distal predictors in the 2019 Healthy Kids Colorado Survey. Prediction standard error = 0.83, cross-validated standard error = 0.93. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 2,755 participants.

model for the data. The prediction error for this tree was 0.83, indicating the tree explained 17% of the variance in this sample. The cross-validation error was 0.93 (95% C.I. = 0.91 - 0.95), meaning that, on average, the tree explained 7% of the variance across cross validation samples,

and that variance explained could range from 5% to 9%. The accuracy rating of this tree was 59.4%. The final tree consisted of six subsamples, three that predicted multiple suicide attempts and three that predicted single suicide attempts. Four predictors were utilized to create these subsamples: the number of times participants engaged in NSSI in the last 12 months (which appeared in the tree twice), if participants created a plan for suicide in the last 12 months, if the participants have ever been physically forced into a sexual encounter they did not want in their lifetime, and an intersection of participant race and ethnicity. The three groups predicted to attempt suicide multiple times were (1) individuals who endorsed engaging in NSSI six or more times in the last 12 months; (2) individuals who endorsed engaging in NSSI five or fewer times in the last 12 months, developed a plan for suicide in the last 12 months, did not provide an answer to the question asking about NSSI, and have been physically forced into a sexual encounter they did not want in their lifetime; and (3) individuals who endorsed engaging in NSSI five or fewer times in the last 12 months, developed a plan for suicide in the last 12 months, did not provide an answer to the question asking about NSSI, have not been physically forced into a sexual encounter they did not want in their lifetime, and they identified as White.

The three groups predicted to attempt suicide one time included (1) individuals who endorsed engaging in NSSI five or fewer times in the last 12 months and did not develop a plan for suicide in the last 12 months; (2) individuals who endorsed engaging in NSSI five or fewer times in the last 12 months but provided an answer to the NSSI question and created a plan for suicide in the last 12 months; and (3) individuals who endorsed engaging in NSSI five or fewer times in the last 12 months, created a plan for suicide in the last 12 months, did not provide an answer to the question asking about NSSI, have not been physically forced into a sexual

encounter they did not want in their lifetime, and identified as being any race or ethnicity other than White.

**Multiple Suicide Attempts Compared to Never Attempting Suicide**

Across the 12 classification trees that analyzed the predictors of multiple suicide attempts compared to never attempting suicide, 10 of the trees were successful in identifying predictors for multiple suicide attempts and one tree demonstrated an immediate increase in the cross-validation error, indicating the tree could only be formed if it was immediately overfit to the data. See Table 6 for a summary of all classification tree parameters that were used to interpret these trees.

***All Predictors for All Participants***

After pruning the 2015 tree exploring all predictors of multiple suicide attempts compared to never attempting suicide, the tree presented in Figure 11 was identified as the best model for the data. The prediction error for this tree was 0.73, indicating the tree explained 27% of the variance in this sample. The cross-validation error was 0.83 (95% C.I. = 0.79 - 0.87), meaning that, on average, the tree explained 17% of the variance across cross validation samples, and that variance explained could range from 13% to 21%. The accuracy rating of this tree was 95.8.7%. The final tree consisted of seven subsamples, three that predicted multiple suicide attempts and four that predicted never attempting suicide. Six predictors were utilized to create these subsamples: if participants developed a plan for suicide in the last 12 months, seriously considered suicide in the last 12 months, the number of days in the last 30 days when participants smoked cigarettes, if they had ever been physically forced into a sexual encounter they did not want in their lifetime, sexual orientation, and the number of times participants misused prescription medication in the last month. The predictor assessing whether participants

**Table 6**

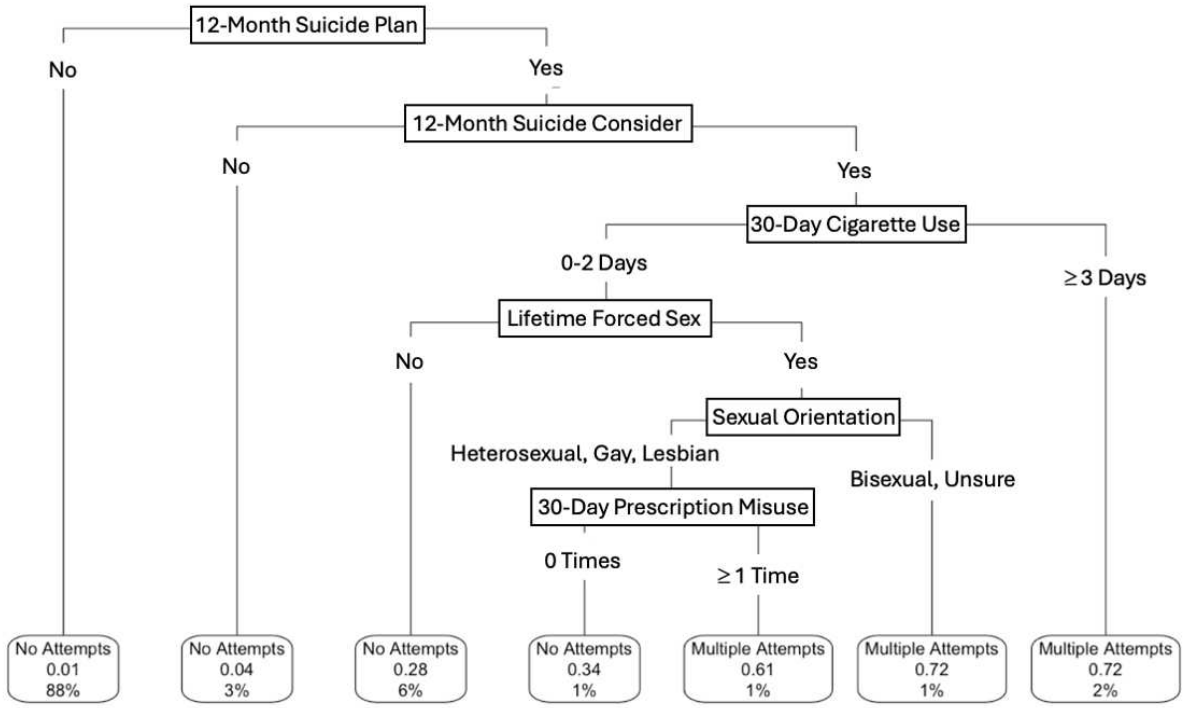
*Classification Tree Parameters Comparing Multiple Suicide Attempts to Never Attempting Suicide in the last 12 Months*

| **Dataset** | *Prediction Error* | *Cross Validation Error* | *Confidence Intervals* | *Accuracy %* | *Sensitivity %* | *Specificity %* | *n* |
|---|---|---|---|---|---|---|---|
| All Variables | | | | | | | |
| 2015 | 0.73 | 0.83 | 0.79 - 0.87 | 95.8 | 97.2 | 54.1 | 10066 |
| 2017 | 0.86 | 0.86 | 0.84 - 0.88 | 96.1 | 96.4 | 76.1 | 32657 |
| 2019 | 0.86 | 0.88 | 0.85 - 0.90 | 96.5 | 96.9 | 71.3 | 32315 |
| Expansive Transgender Identity and/or Sexual Orientation | | | | | | | |
| 2015 | 0.60 | 0.63 | 0.57 - 0.68 | 90.2 | 94.7 | 65.3 | 1470 |
| 2017 | 0.73 | 0.83 | 0.79 - 0.86 | 90.0 | 92.8 | 65.2 | 4658 |
| 2019 | 0.79 | 0.92 | 0.89 - 0.96 | 90.8 | 93.8 | 61.4 | 5201 |
| Proximal Variables Only | | | | | | | |
| 2015 | -- | -- | -- | -- | -- | -- | -- |
| 2017 | 0.91 | 0.92 | 0.89 - 0.94 | 95.6 | 95.8 | 69.7 | 32640 |
| 2019 | 0.94 | 0.97 | 0.94 - 0.99 | 96.1 | 96.2 | 68.1 | 32271 |
| Distal Variables Only | | | | | | | |
| 2015 | 0.79 | 0.8 | 0.76 - 0.84 | 95.9 | 97.3 | 54.5 | 10066 |
| 2017 | -- | -- | -- | -- | -- | -- | -- |
| 2019 | 0.91 | 0.91 | 0.89 - 0.94 | 96.1 | 96.9 | 55.8 | 32315 |

*Note*. The classification tree exploring proximal variables only in the 2015 Health Kids Colorado Survey dataset was not interpreted after the confidence interval surprised 1.0, indicating the tree was overfitting based on the one-minus standard error rule (Breiman et al., 1984). The classification tree exploring distal variables only in the 2017 Health Kids Colorado Survey dataset was not interpreted due to immediate increases in the cross-validation error.

**Figure 11**

*Final Classification Tree for All Predictors and All Participants in 2015 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all participants and all predictors in the 2015 Healthy Kids Colorado Survey. Prediction standard error = 0.73, cross-validated standard error = 0.83. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 10,066 participants.

experienced an injury from suicide in the last 12 months had to be removed from this tree because the tree became a node with this predictor because all participants who experienced an injury attempted suicide multiple times.

The three groups predicted to attempt suicide multiple times were (1) individuals who developed a plan for suicide in the last six months, seriously considered suicide in the last six months, and smoked cigarettes on three or more days in the last month; (2) individuals who developed a plan for suicide in the last six months, seriously considered suicide in the last six months, smoked cigarettes on two or fewer days in the last month, have been physically forced

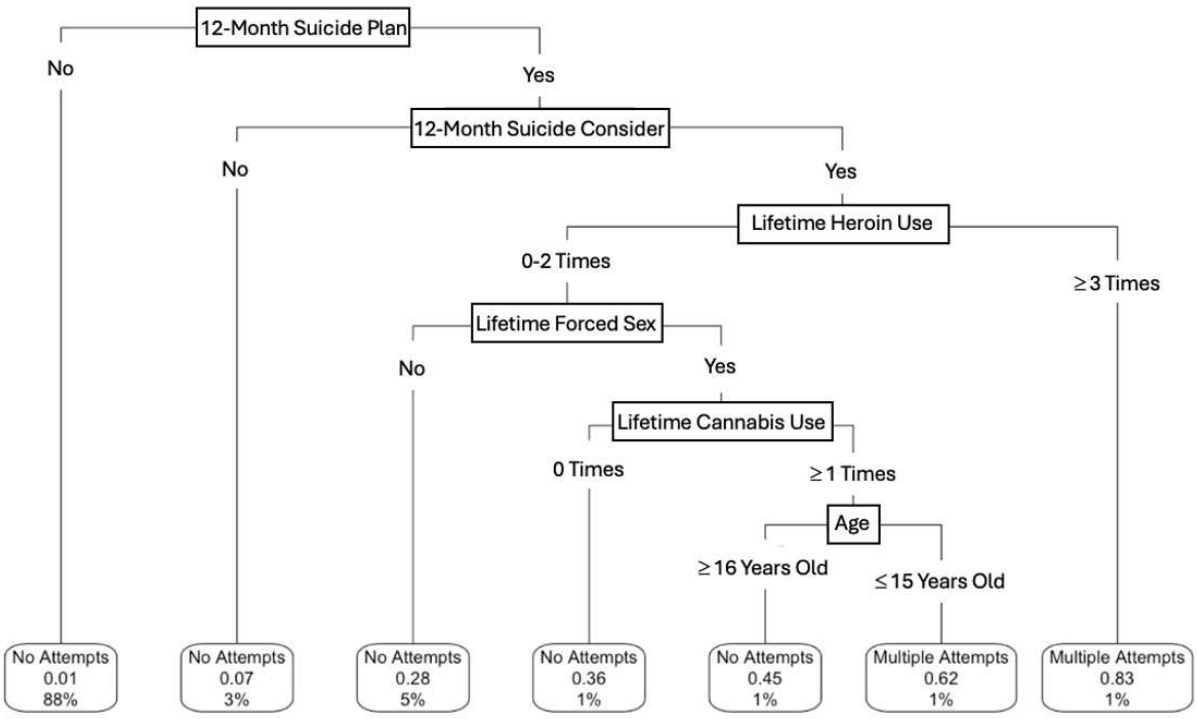
into a sexual encounter they did not want in their lifetime, and they are bisexual or unsure of their sexual orientation; and (3) individuals who developed a plan for suicide in the last six months, seriously considered suicide in the last six months, smoked cigarettes on two or fewer days in the last month, have been physically forced into a sexual encounter they did not want in their lifetime, they are heterosexual, gay, or lesbian, and they have not misused prescription medications in the last month.

The four groups predicted to never attempt suicide included (1) individuals who did not develop a plan for suicide in the last 12 months; (2) individuals who developed a plan for suicide and did not seriously consider suicide in the last 12 months; (3) individuals who developed a plan for suicide in the past 12 months, seriously considered suicide in the past 12 months, smoked cigarettes on two or fewer days in the last month, and have not been physically forced in a sexual encounter they did not want in their lifetime; and (4) individuals who developed a plan for suicide in the past 12 months, seriously considered suicide in the past 12 months, smoked cigarettes on two or fewer days in the last month, have been physically forced in a sexual encounter they did not want in their lifetime, identified as heterosexual, gay, or lesbian, and did not misuse prescription medication in the last month.

After pruning the 2017 tree exploring all predictors of multiple suicide attempts compared to never attempting suicide, the tree presented in Figure 12 was identified as the best model for the data. The prediction error for this tree was 0.86, indicating the tree explained 14% of the variance in this sample. The cross-validation error was 0.86 (95% C.I. = 0.84 - 0.88), meaning that, on average, the tree explained 14% of the variance across cross validation samples, and that variance explained could range from 12% to 16%. The accuracy rating of this tree was 96.1%. The final tree consisted of seven subsamples, two that predicted multiple suicide attempts

**Figure 12**

*Final Classification Tree for All Predictors and All Participants in 2017 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all participants and all predictors in the 2017 Healthy Kids Colorado Survey. Prediction standard error = 0.86, cross-validated standard error = 0.86. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 32,657 participants.

and five that predicted never attempting suicide. Six predictors were utilized to create these subsamples: creating a plan for suicide in the last 12 months, seriously considering suicide in the last 12 months, the number of times someone used heroin in their lifetime, if participants have ever been physically forced to have a sexual encounter they did not want, the number of times someone used cannabis in their lifetime, and participant age. The two groups predicted to attempt suicide multiple times were (1) individual who created a plan for suicide in the last 12 months, seriously considered suicide in the last 12 months, and used heroin three or more times in their

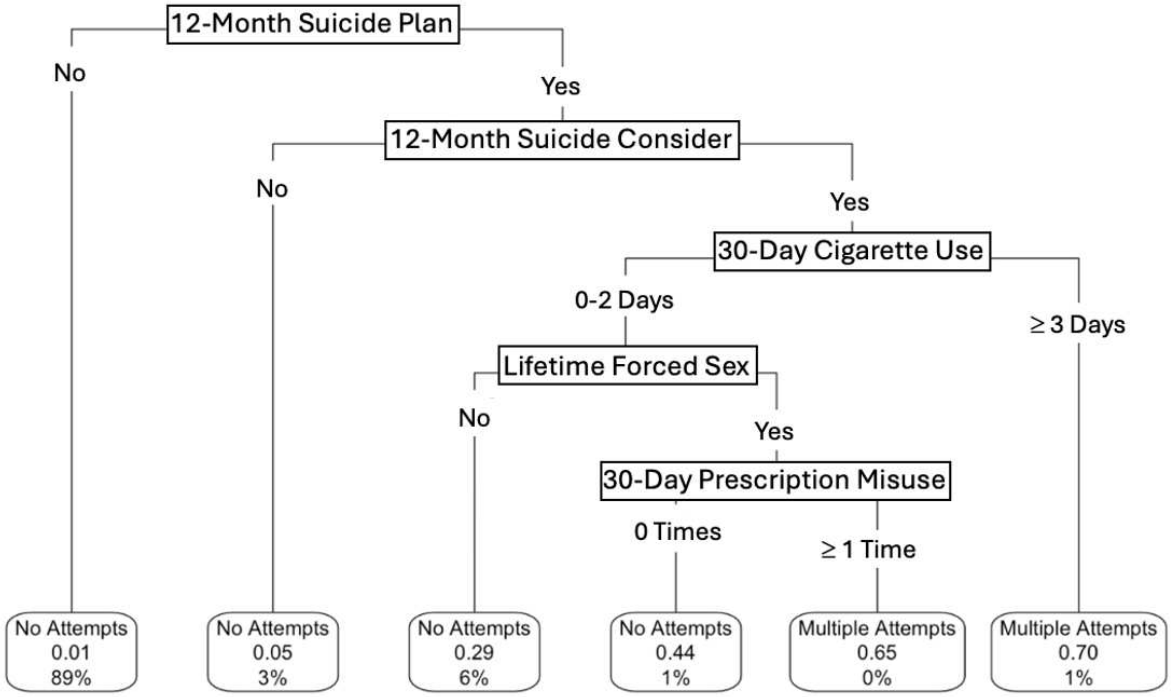
lifetime; and (2) individual who created a plan for suicide in the last 12 months, seriously considered suicide in the last 12 months, used heroin three or fewer times in their lifetime; have been physically forced into a sexual encounter they did not want in their lifetime, used cannabis one or more times in their lifetime, and they are 15 years old or younger.

The five groups predicted to never attempt suicide included (1) individuals who did not create a plan for suicide in the last 12 months; (2) individuals who created a plan for suicide but did not seriously consider suicide in the last 12 months; (3) individuals who created a plan for and seriously considered suicide in the last 12 months, used heroin two or fewer times in their lifetime, and have not been physically forced into a sexual encounter they did not want in their lifetime; (4) individuals who created a plan for and seriously considered suicide in the last 12 months, used heroin two or fewer times in their lifetime, have been physically forced into a sexual encounter they did not want in their lifetime, and have not used cannabis in their lifetime; and (5) individuals who created a plan for and seriously considered suicide in the last 12 months, used heroin two or fewer times in their lifetime, have been physically forced into a sexual encounter they did not want in their lifetime, have used cannabis one or more times in their lifetime, and are 16 years old or older.

After pruning the 2019 tree exploring all predictors of multiple suicide attempts compared to never attempting suicide, the tree presented in Figure 13 was identified as the best model for the data. The prediction error for this tree was 0.86, indicating the tree explained 14% of the variance in this sample. The cross-validation error was 0.88 (95% C.I. = 0.85 - 0.90), meaning that, on average, the tree explained 12% of the variance across cross validation samples, and that variance explained could range from 10% to 15%. The accuracy rating of this tree was 96.5%. The final tree consisted of six subsamples, two that predicted multiple suicide attempts

**Figure 13**

*Final Classification Tree for All Predictors and All Participants in 2019 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all participants and all predictors in the 2019 Healthy Kids Colorado Survey. Prediction standard error = 0.86, cross-validated standard error = 0.88. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 32,315 participants.

and four that predicted never attempting suicide. Five predictors were utilized to create these subsamples: developing a plan for suicide in the last 12 months, seriously considering suicide in the last 12 months, the number of days in the last month when participants smoked cigarettes, if participants have been physically forced into a sexual encounter they did not want in their lifetime, and the number of times participants misused prescription medication in the last month. The two groups predicted to attempt suicide multiple times were (1) individuals who developed a plan for and seriously consider suicide in the last 12 months and smoked cigarettes on three or

more days in the last month, and (2) individuals who developed a plan for and seriously consider suicide in the last 12 months, smoked cigarettes on two or fewer days in the last month, have been physically forced into a sexual encounter they did not want in their lifetime, and misused prescription medication one or more times in the last month.

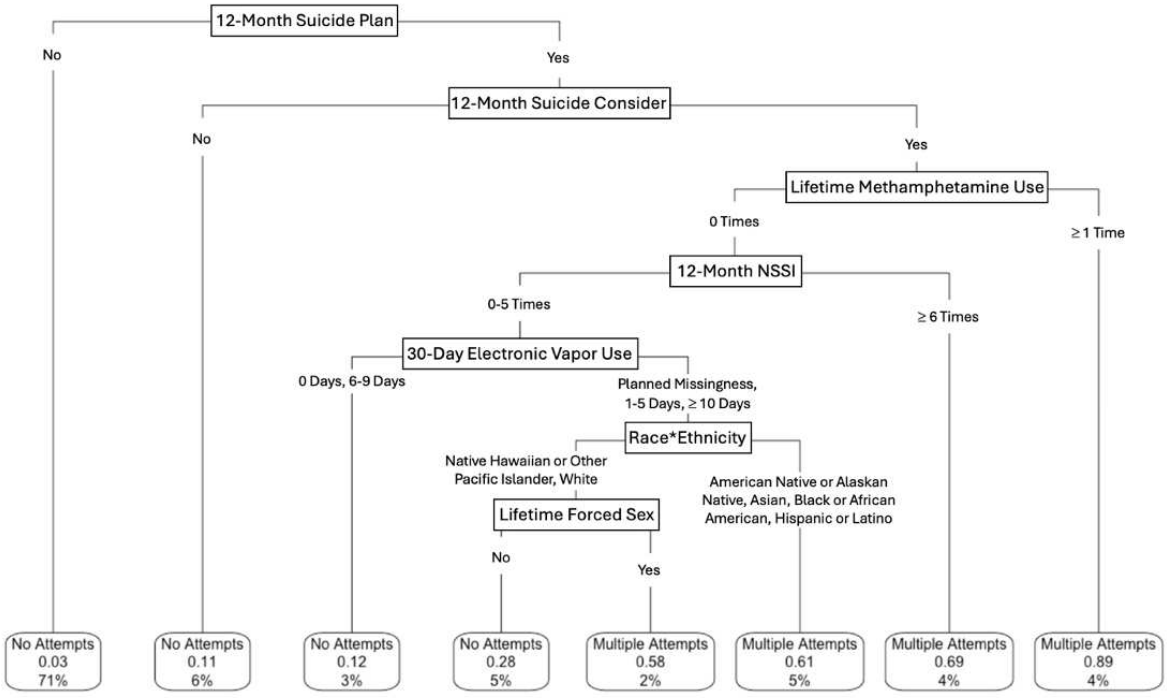
The four groups predicted to never attempt suicide included (1) individuals who did not create a plan for suicide in the last 12 months; (2) individuals who developed a plan for but did not seriously consider suicide in the last 12 months; (3) individuals who developed a plan for and seriously consider suicide in the last 12 months, smoked cigarettes on two or fewer days in the last month, and have not been physically forced into a sexual encounter they did not want in their lifetime; and (4) individuals who developed a plan for and seriously consider suicide in the last 12 months, smoked cigarettes on two or fewer days in the last month, have been physically forced into a sexual encounter they did not want in their lifetime, and did not misuse prescription medication in the last month.

***All Predictors for Participants with Expansive Gender Identity and/or Sexual Orientation***

After pruning the 2015 tree exploring all predictors of multiple suicide attempts compared to never attempting suicide for individuals with expansive gender identity or sexual orientation is presented in Figure 14. The prediction error for this tree was 0.60, indicating the tree explained 40% of the variance in this sample. The cross-validation error was 0.63 (95% C.I. = 0.57 - 0.68), meaning that, on average, the tree explained 37% of the variance across cross validation samples, and that variance explained could range from 32% to 43%. The accuracy rating of this tree was 90.2%. The final tree consisted of eight subsamples, four that predicted multiple suicide attempts and four that predicted never attempting suicide. Seven predictors were utilized to create these subsamples: if the participants created a plan for suicide in the last 12

**Figure 14**

*Final Classification Tree for All Predictors and Participants who Identified with an Expansive Gender Identity or Sexual Orientation in 2015 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all predictors and only participants who identified with an expansive gender identity or sexual orientation in the 2015 Healthy Kids Colorado Survey. Prediction standard error = 0.60, cross-validated standard error = 0.63. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 1,470 participants.

months, if participants seriously considered suicide in the last 12 months, the number of times they have used methamphetamine in their lifetime, the number of times they have engaged in NSSI in the past 12 months, the number of times they used an electronic vapor product in the last month, an intersection of participant race and ethnicity, and if the participants have ever been physically forced into a sexual encounter they did not want in their lifetime.

The four groups predicted to attempt suicide multiple times were (1) individuals who developed a plan for and seriously considered suicide in the last 12 months and used

methamphetamine one or more times in their lifetime; (2) individuals who developed a plan for and seriously considered suicide in the last 12 months, did not use methamphetamine in their lifetime, and engaged in NSSI six or more times in the last 12 months; (3) individuals who developed a plan for and seriously considered suicide in the last 12 months, did not use methamphetamine in their lifetime, engaged in NSSI five or fewer times in the last 12 months, used an electronic vapor product between zero and five days or 10 or more days in the last month, and identified as American Indian or Alaska Native, Asian, Black or African American, or Hispanic or Latino; and (4) individuals who developed a plan for and seriously considered suicide in the last 12 months, did not use methamphetamine in their lifetime, engaged in NSSI five or fewer times in the last 12 months, used an electronic vapor product between zero and five days or 10 or more days in the last month, identified as Native Hawaiian or Pacific Islander or White, and endorsed being physically forced into a sexual encounter they did not want in their lifetime.

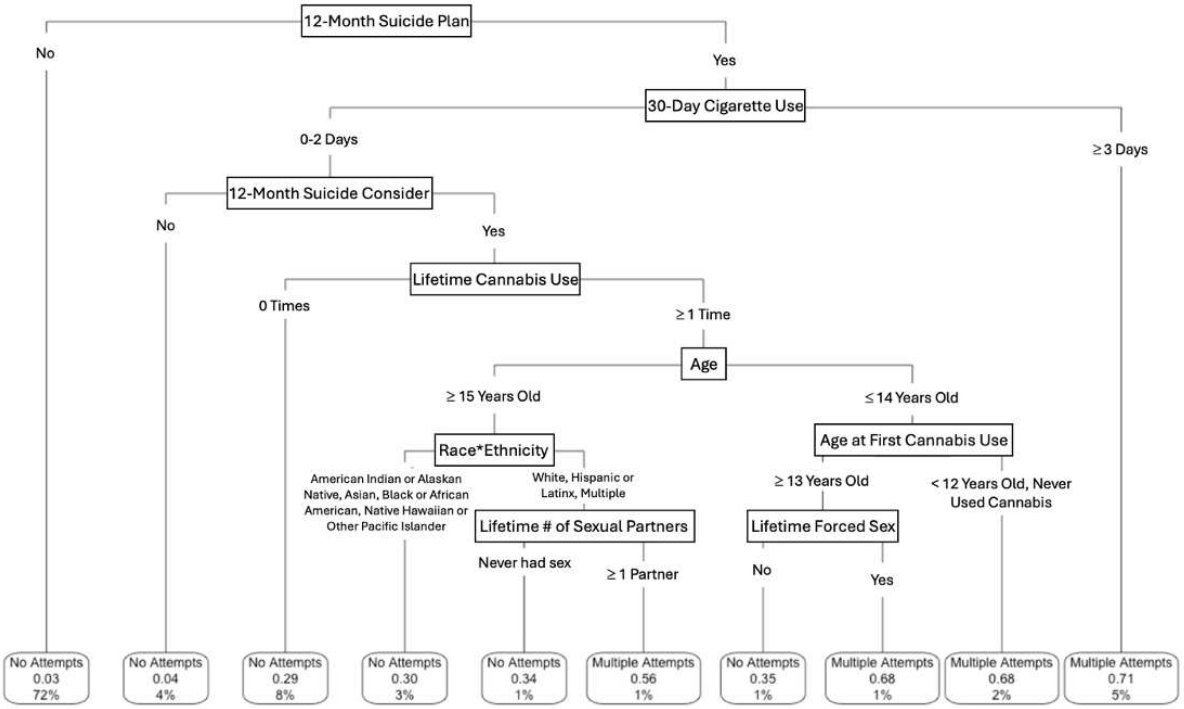
The four groups predicted to never attempt suicide were (1) individuals who did not develop a plan for suicide in the last 12 months; (2) individuals who developed a plan for but did not seriously considered suicide in the last 12 months; (3) individuals who developed a plan for and seriously considered suicide in the last 12 months, did not use methamphetamine in their lifetime, engaged in NSSI five or fewer times in the last 12 months, and either did not use electronic vapor products or used them six to 9 times in the last month; and (4) individuals who developed a plan for and seriously considered suicide in the last 12 months, did not use methamphetamine in their lifetime, engaged in NSSI five or fewer times in the last 12 months, used an electronic vapor product between zero and five days or 10 or more days in the last

month, identified as Native Hawaiian or Pacific Islander or White, and have not been physically forced into a sexual encounter they did not want in their lifetime.

After pruning the 2017 tree exploring all predictors of multiple suicide attempts compared to never attempting suicide for individuals with expansive gender identity or sexual orientation is presented in Figure 15. The prediction error for this tree was 0.73, indicating the

**Figure 15**

*Final Classification Tree for All Predictors and Participants who Identified with an Expansive Gender Identity or Sexual Orientation in 2017 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all predictors and only participants who identified with an expansive gender identity or sexual orientation in the 2017 Healthy Kids Colorado Survey. Prediction standard error = 0.73, cross-validated standard error = 0.83. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 4,658 participants.

tree explained 27% of the variance in this sample. The cross-validation error was 0.83 (95% C.I. = 0.79 - 0.86), meaning that, on average, the tree explained 17% of the variance across cross

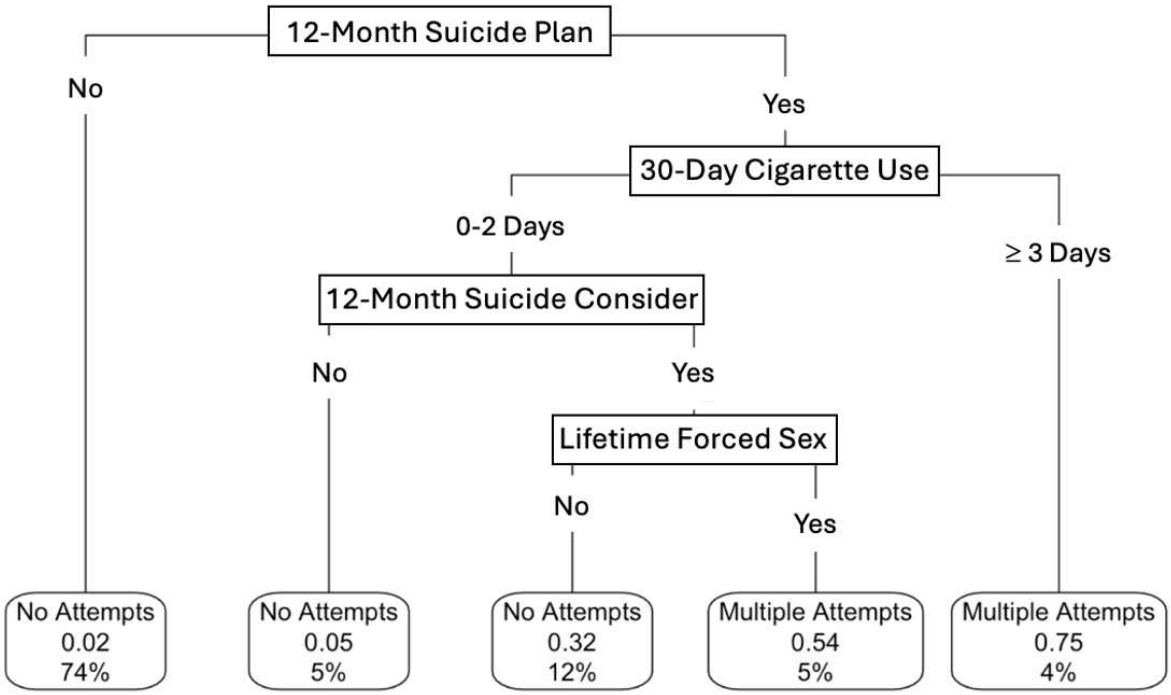
validation samples, and that variance explained could range from 14% to 21%. The accuracy rating of this tree was 90.0%. The final tree consisted of 10 subsamples, four that predicted multiple suicide attempts and six that predicted never attempting suicide. Nine predictors were utilized to create these subsamples: if the participants created a plan for suicide in the last 12 months, the number of days on which they smoked cigarettes in the last month, if participants seriously considered suicide in the last 12 months, the number of times they have used cannabis in their lifetime, participant age, an intersection of participant race and ethnicity, the age at which participants first used cannabis, the number of sexual partners the participants have had in their lifetime, and if the participants have ever been physically forced into a sexual encounter they did not want in their lifetime.

Given its size, the full tree is depicted in Figure 15. The group predicted to be at the highest risk for attempting suicide multiple times were individuals who developed a plan for suicide in the last 12 months and smoked cigarettes on three or more days in the last month. The group at the next highest risk group for attempting suicide multiple times consisted of individuals who developed a plan for suicide, smoked cigarettes on two or fewer days in the last month, seriously considered suicide in the last 12 months, endorsed using cannabis one or more times in their lifetime, were 15 years old or younger, and first used cannabis before the age of 12 or have never used cannabis in their lifetime. The group predicted to be the most likely to never attempt suicide were individuals who did not develop a plan for suicide in the last 12 months. The next group most likely to never attempt suicide included individuals who created a plan for suicide, smoked cigarettes on two or fewer days in the last month, and did not seriously consider suicide in the last 12 months.

After pruning the 2019 tree exploring all predictors of multiple suicide attempts compared to never attempting suicide for individuals with expansive gender identity or sexual orientation is presented in Figure 16. The prediction error for this tree was 0.79, indicating the

**Figure 16**

*Final Classification Tree for All Predictors and Participants who Identified with an Expansive Gender Identity or Sexual Orientation in 2019 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all predictors and only participants who identified with an expansive gender identity or sexual orientation in the 2019 Healthy Kids Colorado Survey. Prediction standard error = 0.79, cross-validated standard error = 0.92. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 5,201 participants.

tree explained 21% of the variance in this sample. The cross-validation error was 0.92 (95% C.I. = 0.89 - 0.96), meaning that, on average, the tree explained 8% of the variance across cross validation samples, and that variance explained could range from 4% to 11%. The accuracy

rating of this tree was 90.8%. The final tree consisted of five subsamples, two that predicted multiple suicide attempts and three that predicted never attempting suicide. Four predictors were utilized to create these subsamples: if the participants created a plan for suicide in the last 12 months, the number of days on which they smoked cigarettes in the last month, if participants seriously considered suicide in the last 12 months, and if the participants have ever been physically forced into a sexual encounter they did not want in their lifetime.

The two groups predicted to attempt suicide multiple times were (1) individuals who developed a plan for in the last 12 months and smoked cigarettes on three or more days in the last month and (2) individuals who developed a plan for suicide in the last 12 months, smoked cigarettes on two or fewer days in the last month, seriously considered suicide in the last 12 months, and have been physically forced into a sexual encounter they did not want in their lifetime. The three groups predicted to never attempt suicide were (1) individuals did not develop a plan for in the last 12 months; (2) individuals who developed a plan for suicide in the last 12 months, smoked cigarettes on two or fewer days in the last month, and did not seriously consider suicide in the last 12 months; and (3) individuals who developed a plan for suicide in the last 12 months, smoked cigarettes on two or fewer days in the last month, seriously considered suicide in the last 12 months, and have not been physically forced into a sexual encounter they did not want in their lifetime.

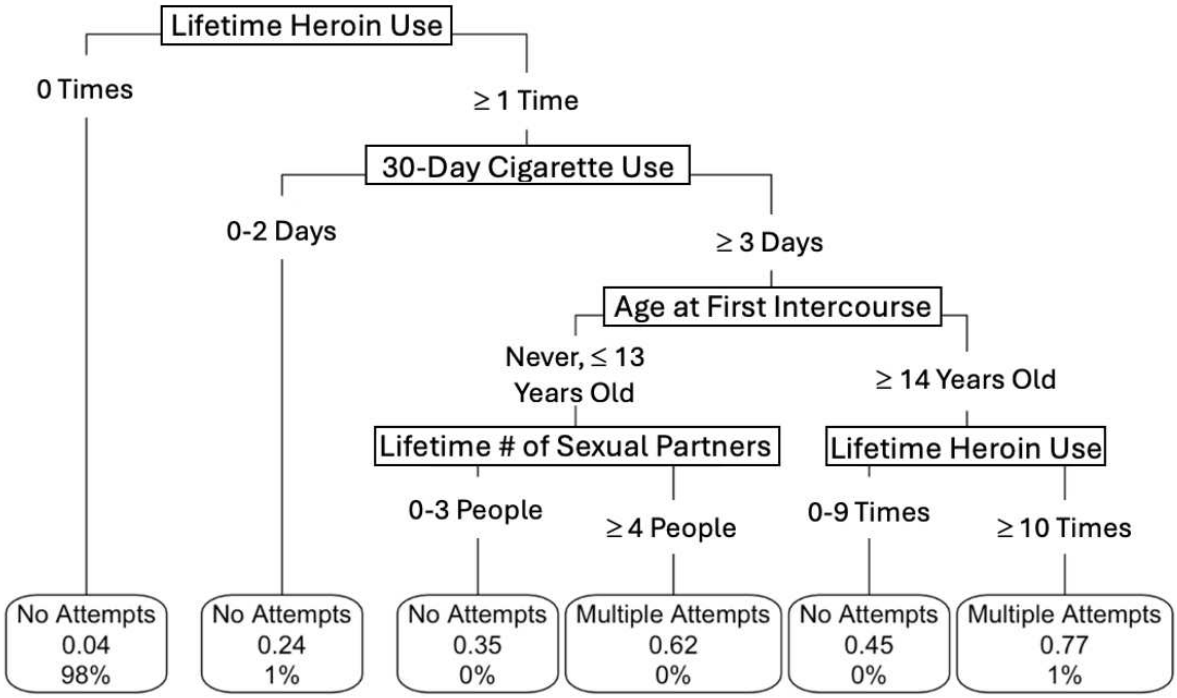
***Proximal Predictors Only***

After pruning the 2015 tree exploring only the proximal predictors of multiple suicide attempts compared to never attempting suicide, the prediction error for this tree was 0.95, indicating the tree explained 5% of the variance in this sample. The cross-validation error was 1.00 (95% C.I. = 0.95 - 1.05), meaning that the tree was overfit based on the one-minus standard

error rule (Breiman et al., 1984). Therefore, this model was not interpreted further. After pruning the 2017 tree exploring only the proximal predictors of multiple suicide attempts compared to never attempting suicide, the tree presented in Figure 17 was identified as the best model for the

**Figure 17**

*Final Classification Tree for All Participants and Proximal Predictors Only in 2017 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all participants and only proximal predictors in the 2017 Healthy Kids Colorado Survey. Prediction standard error = 0.91, cross-validated standard error = 0.92. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 32,640 participants.

data. The prediction error for this tree was 0.91, indicating the tree explained 9% of the variance in this sample. The cross-validation error was 0.92 (95% C.I. = 0.89 - 0.94), meaning that, on average, the tree explained 8% of the variance across cross validation samples, and that variance explained could range from 6% to 11%. The accuracy rating of this tree was 95.6%.

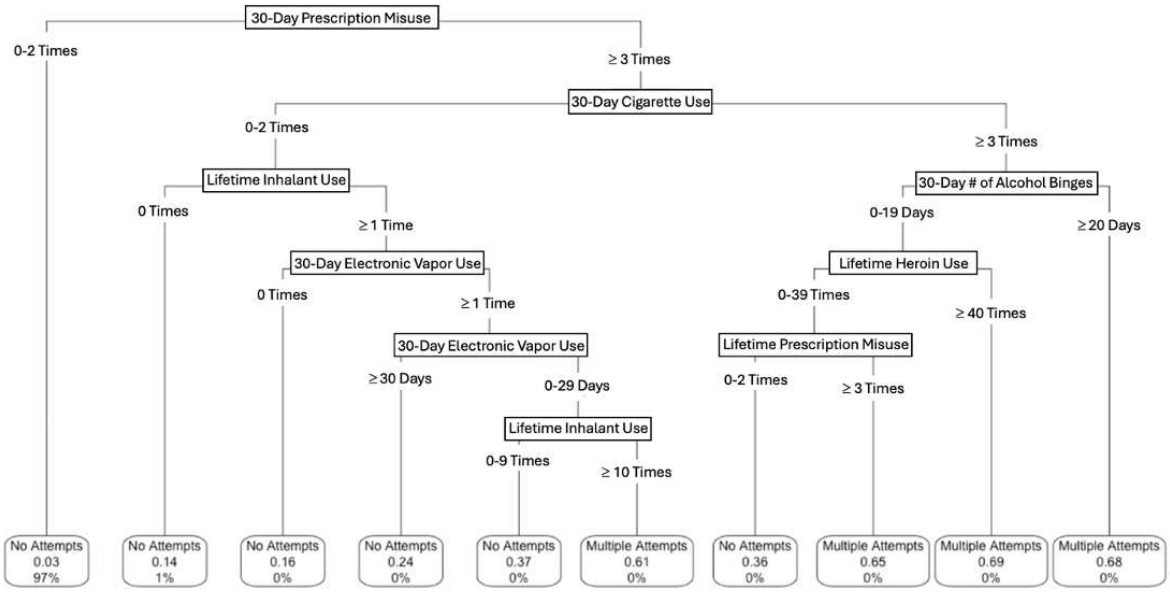
The final tree consisted of six subsamples, two that predicted multiple suicide attempts and four that predicted never attempting suicide. Four predictors were utilized to create these subsamples: the number of times the participants used heroin in their lifetime (which appeared in the tree twice), how many days in the last month they smoked cigarettes, participant age during first sexual intercourse, and the number of partners the participants have had in their lifetime. The two groups predicted to attempt suicide multiple times were (1) individuals who used heroin one or more times in their lifetime, smoked cigarettes on three or more days in the last month, were 12 years old or younger when they first had sexual intercourse or they have never had sexual intercourse, and used heroin 10 or more times in their lifetime and (2) individuals who used heroin one or more times in their lifetime, smoked cigarettes on three or more days in the last month, were 13 years old or older when they first had sexual intercourse, and had four or more sexual partners in their lifetime.

The four groups predicted to never attempt suicide included (1) individuals who never used heroin in their lifetime; (2) individuals who used heroin one or more times in their lifetime and smoked cigarettes on two or fewer days in the last month; (3) individuals who used heroin one or more times in their lifetime, smoked cigarettes on three or more days in the last month, were 13 years old or older when they first had sexual intercourse, and had three or fewer sexual partners in their lifetime; and (4) individuals who used heroin one or more times in their lifetime, smoked cigarettes on three or more times in the last month, were 12 years old or younger when they first had sexual intercourse or they have never had sexual intercourse, and used heroin nine or fewer times in their lifetime.

After pruning the 2019 tree exploring only the proximal predictors of multiple suicide attempts compared to never attempting suicide, the tree presented in Figure 18 was identified as

**Figure 18**

*Final Classification Tree for All Participants and Proximal Predictors Only in 2019 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all participants and only proximal predictors in the 2019 Healthy Kids Colorado Survey. Prediction standard error = 0.94, cross-validated standard error = 0.97. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 32,271 participants.

the best model for the data. The prediction error for this tree was 0.94, indicating the tree explained 6% of the variance in this sample. The cross-validation error was 0.97 (95% C.I. = 0.94 - 0.99), meaning that, on average, the tree explained 3% of the variance across cross validation samples, and that variance explained could range from 1% to 6%. The accuracy rating of this tree was 96.1%. This tree must be interpreted with caution because the cross-validation error indicates that this model is only slightly better than chance in predicting the outcome. The final tree consisted of 10 subsamples, four that predicted multiple suicide attempts and six that predicted never attempting suicide. Seven predictors were utilized to create these subsamples:

the number of day in the last month when participants misused prescription medications, the number of days in the last month when participant smoked cigarettes, the number of times participants sniffed glue, breathed the contents of aerosol spray cans, or inhaled any paints or sprays to get high in their lifetime (which appeared in the tree twice), the number of times in the last month when participants used electronic vapor products (which appeared in the tree twice), the number of times in the last month when participants binged on alcoholic beverages (defined as four or more alcoholic beverages in a row females and five or more for males in a couple of hours), the number of times participants used heroin in their lifetime, and the number of times participants misused prescription medication in their lifetime.

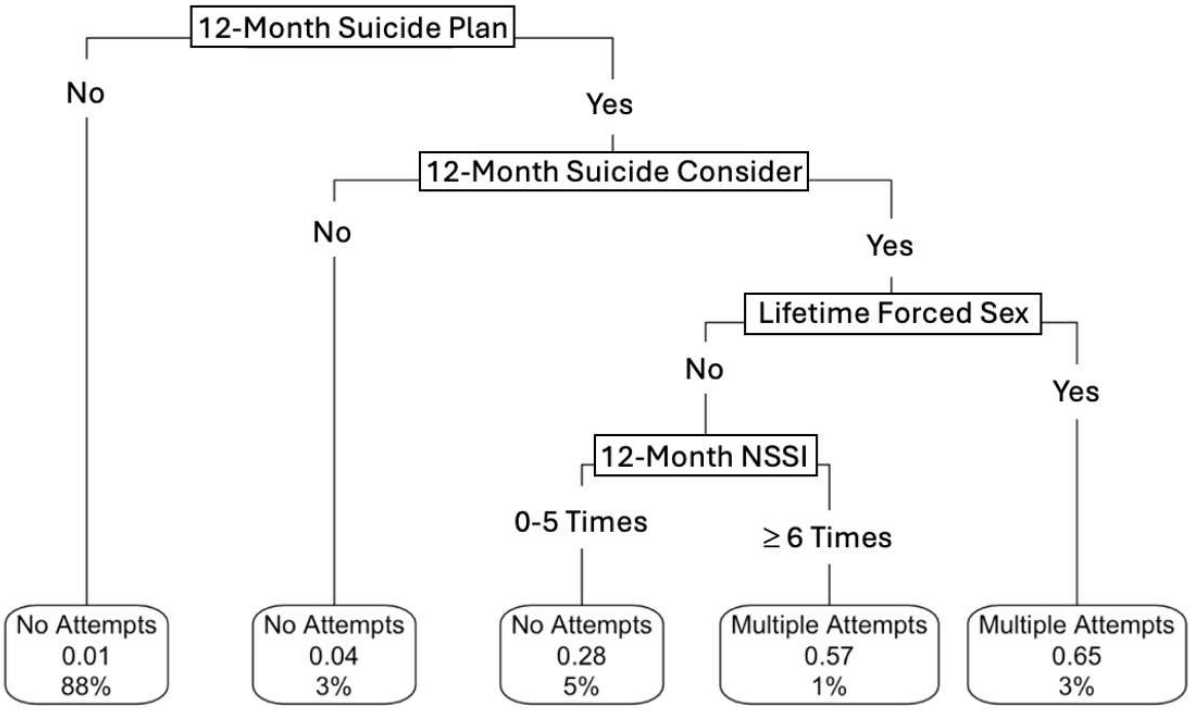
Given its size, the full tree is depicted in Figure 18. The group predicted to be at the highest risk for attempting suicide multiple times were individuals who misused prescription medication three or more times in the last month, smoked cigarettes on three or more days in the last month, and engaged in seven or more alcohol binges in their lifetime. The group at the next highest risk group for attempting suicide multiple times consisted of individuals who misused prescription medication three or more times in the last month, smoked cigarettes on three or more days in the last month, engaged in six or fewer alcohol binges in their lifetime, and used heroin 40 or more times in the lifetime. The group predicted to be the most likely to never attempt suicide were individuals who misused prescription medication two or fewer times in the last month. The next group most likely to never attempt suicide included individuals who misused prescription medication three or more times in the last month and never sniffed glue, breathed the contents of aerosol spray cans, or inhaled any paints or sprays to get high in their lifetime.

### *Distal Predictors Only*

One of the three trees exploring only the distal predictors of multiple suicide attempts compared to never attempting suicide for all participants demonstrated an immediate increase in the cross-validation error, indicating the tree was overfit and could not be interpreted accurately. Therefore, the tree for the 2017 dataset was not interpreted. After pruning the 2015 tree exploring only the distal predictors of multiple suicide attempts compared to never attempting suicide, the tree presented in Figure 19 was identified as the best possible model for the data. The

**Figure 19**

*Final Classification Tree for All Participants and Distal Predictors Only in 2015 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all participants and only distal predictors in the 2015 Healthy Kids Colorado Survey. Prediction standard error = 0.79, cross-validated standard error = 0.80. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 10,066 participants.

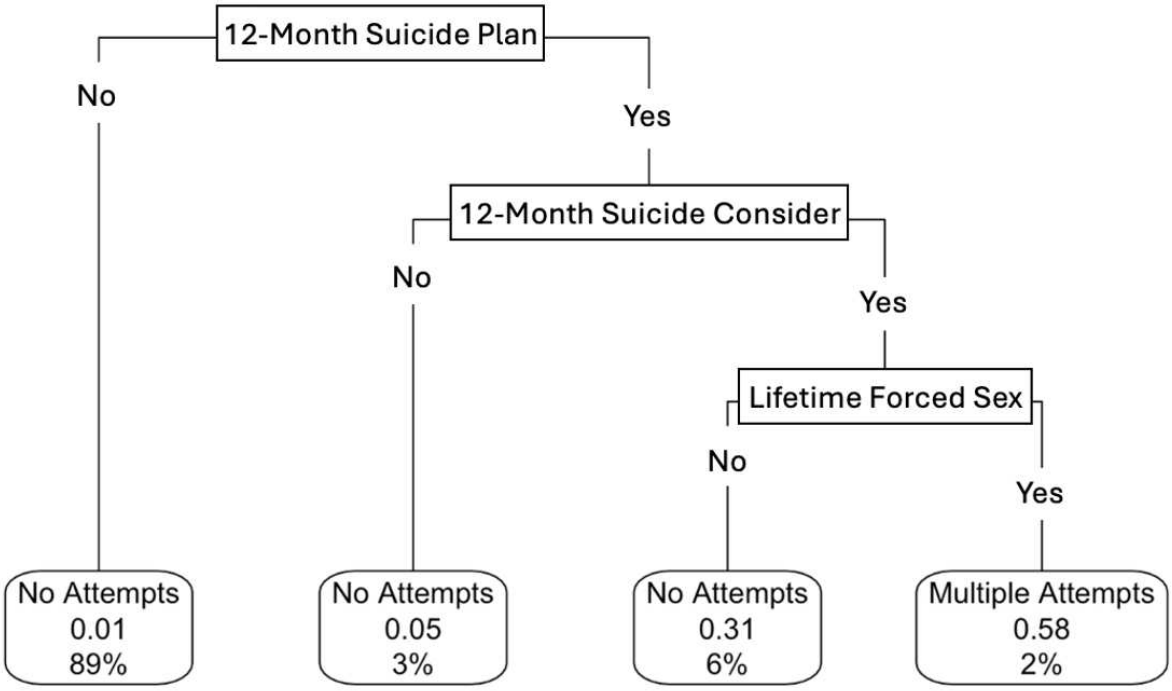
prediction error for this tree was 0.79, indicating the tree explained 21% of the variance in this sample. The cross-validation error was 0.80 (95% C.I. = 0.76 - 0.84), meaning that, on average, the tree explained 20% of the variance across cross validation samples, and that variance explained could range from 16% to 24%. The accuracy rating of this tree was 95.9%. The final tree consisted of five subsamples, two that predicted multiple suicide attempts and three that predicted never attempting suicide. Four predictors were utilized to create these subsamples: if participant made a plan for suicide in the last 12 months, if they seriously considered suicide in the last 12 months, if they have ever been physically forced into a sexual encounter they did not want in their lifetime, and the number of times they engaged in NSSI in the last 12 months. The predictor assessing whether participants experienced an injury from suicide in the last 12 months had to be removed from this tree because the tree became a node with this predictor because all participants who experienced an injury attempted suicide multiple times.

The two groups predicted to attempt suicide multiple times were (1) individuals who made a plan for and seriously considered suicide in the last 12 months and have been physically forced into a sexual encounter they did not want in their lifetime and (2) individuals who made a plan for and seriously considered suicide in the last 12 months, have not been physically forced into a sexual encounter they did not want in their lifetime, and engaged in NSSI six or more times in the last 12 months. The three groups predicted to never attempt suicide included (1) individuals who did not create a plan for suicide in the last 12 months; (2) individuals who developed a plan for suicide but did not seriously consider it in the last 12 months; and (3) individuals who made a plan for and seriously considered suicide in the last 12 months, have not been physically forced into a sexual encounter they did not want in their lifetime, and engaged in NSSI five or fewer times in the last 12 months.

After pruning the 2019 tree exploring only the distal predictors of multiple suicide attempts compared to never attempting suicide, the tree presented in Figure 20 was identified as

**Figure 20**

*Final Classification Tree for All Participants and Distal Predictors Only in 2019 Predicting Multiple and Never Attempting Suicide*




*Note.* Final classification tree depicting the prediction of multiple suicide attempts and never attempting suicide across all participants and only distal predictors in the 2019 Healthy Kids Colorado Survey. Prediction standard error = 0.91, cross-validated standard error = 0.91. Noted below each terminal node are the predicted probability of attempting suicide multiple times and the percentage of observations in that node. Estimation was based on 32,315 participants.

the best possible model for the data. The prediction error for this tree was 0.91, indicating the tree explained 9% of the variance in this sample. The cross-validation error was 0.91 (95% C.I. = 0.89 – 0.94), meaning that, on average, the tree explained 9% of the variance across cross validation samples, and that variance explained could range from 6% to 11%. The accuracy rating of this tree was 96.1%. The final tree consisted of four subsamples, one that predicted

multiple suicide attempts and three that predicted never attempting suicide. Three predictors were utilized to create these subsamples: if participant made a plan for suicide in the last 12 months, if they seriously considered suicide in the last 12 months, and if they have ever been physically forced into a sexual encounter they did not want in their lifetime. The group predicted to attempt suicide multiple times was individuals who made a plan for and seriously considered suicide in the last 12 months and have been physically forced into a sexual encounter they did not want in their lifetime. The three groups predicted to never attempt suicide included (1) individuals who did not create a plan for suicide in the last 12 months; (2) individuals who developed a plan for suicide but did not seriously consider it in the last 12 months; and (3) individuals who made a plan for and seriously considered suicide in the last 12 months and have not been physically forced into a sexual encounter they did not want in their lifetime.

# Chapter 4 - Discussion

In accordance with previous studies investigating the utilization of machine learning on self-injurious thoughts and behaviors (Burke et al., 2019; Burke et al., 2020; Wallace et al., 2020), the present study sought to identify intersecting identity factors and interacting health risk behaviors that best predicted multiple suicide attempts among Colorado adolescents. Several themes emerged across the predictors identified as most indicative of multiple suicide attempts for Colorado adolescents. The present study investigated predictors of multiple suicide attempts both compared to individuals who never attempted suicide and those who only attempted suicide once to best capture any possible predictive differences across these populations. Nineteen significant predictors were identified when exploring multiple suicide attempts compared to never attempting suicide, and 16 predictors were identified when exploring multiple suicide attempts compared to single suicide attempts. Additionally, a greater number of proximal variables were identified as salient predictors of multiple suicide attempts in the models using never attempting suicide as the comparison group, and these variables did not appear in the models using single suicide attempts as the comparison group. These proximal predictors included the number of times participants used cannabis, methamphetamine, and sniffed glue, breathed the contents of aerosol spray cans, or inhaled any paints or sprays to get high in their lifetime; how many times in the last month participants used electronic vapor products and binged on alcohol; participant age when they first used cannabis and when they first had sexual intercourse; and the total number of sexual partners in the participants' lifetime.

These differences in both the total number of significant predictors and the type of predictors identified for the different comparison groups could indicate that there is a larger

number of differences between those who never attempt suicide and those who attempt suicide one or more times. This possibility is supported by previous research studies purporting that those who attempt suicide multiple times are more likely to endorse psychotic disorders (Stoliker, 2021), PTSD (Park et al., 2020), mood disorders (Pennel et al., 2018), personality disorders (Sinclair et al., 2016), a history of childhood trauma (Cankaya et al., 2011), substance use (Icick et al., 2018), family history of mental illness (Icick et al., 2019), and stressful life events (Okan İbiloğlu et al., 2016) compared to those who attempt suicide once.

This deduction must be interpreted with caution though. The present research sample was heavily dominated by individuals who never attempted suicide (91.47% of the sample) and the percentages of participants who attempted suicide once was comparable to the number of participants who attempted suicide multiple times (4.38% and 4.16%, respectively). Furthermore, the stopping rules utilized in the present study to limit the number of observations necessary for a split to occur in the tree and the minimum number of observations necessary to fill a terminal node were held constant across all of the trees in order to enable comparisons across trees. Therefore, it is possible that the disparities in the number of significant predictors identified for each comparison group was a product of the difference in samples sizes and the static stopping rules instead of true differences between the comparison groups. Replicated research needs to be conducted with comparable sample sizes across the comparison groups to discern if the disparities in the number and type of predictors identified for each group is due to qualitative differences between those who attempt suicide and those who do not attempt suicide.

The most common predictors of multiple suicide attempts included developing a plan for suicide in the last 12 months, seriously considering suicide in the last 12 months, being physically forced into an unwanted sexual encounter in one's lifetime, the number of times

someone engaged in NSSI in the last 12 months, and the number of days in the last month when someone smoked cigarettes. In order, the following predictors were identified as the most predictive salient correlates (the ones that prompted the first split of the tree) of multiple suicide attempts: Developing a plan for suicide in the last 12 months, the number of times participants used heroin in their lifetime, the number of times in the past month when participant misused prescription medications, and the number of days in the last month when participants smoked cigarettes. In no particular order, the remaining variables that were identified as the primary predictors of multiple attempts included engagement in NSSI over the last 12 months, being physically forced into an unwanted sexual encounter in one's lifetime, transgender identity, and the number of times in the last month someone drank alcohol. All remaining predictors that appeared in the classification trees only appeared as interactions with these variables and/or through intersecting sociodemographic predictors.

Developing a plan for suicide in the last 12 months was the most common predictor of suicide, appearing as the initial predictor in eight of the 20 trees evaluated. Although often thought of as a precursor to planning a suicide attempt (Castellví et al., 2017; McLoughlin et al., 2015; Ribeiro et al., 2016), thinking about and seriously considering suicide only appeared as a significant predictor of multiple attempts in interaction with and after the predictor for creating a plan for suicide in the present study. For example, seriously considering suicide in the past 12 months appeared directly after creating a plan for suicide in the last 12 months in all three trees exploring all predictors of multiple attempts compared to never attempting suicide, both trees exploring only distal predictors of multiple suicide attempts compared to never attempting suicide, and the 2015 tree exploring multiple suicide attempts compared to never attempting suicide among participants with one or more non-dominant sexual orientation or transgender

identity. This pattern would imply that seriously considering suicide is only a significant predictor of multiple attempts in interaction with creating a plan for suicide. The two trees exploring predictors of multiple suicide attempts compared to never attempting suicide among participants with non-dominant sexual orientation and transgender identities also identified seriously considering suicide in the last 12 months as a salient predictor of multiple suicide attempts after both creating a plan for suicide and a greater number of times that participants smoked cigarettes in the past month. For this participant sample specifically, this pattern indicates that seriously considering suicide is only an increased risk factor in the presence of both developing a plan for suicide and smoking cigarettes more often in the last month.

These findings stand in contrast to the Interpersonal-Psychology Theory of Suicide Behavior model proposed by Joiner (2005) as well as findings from other researchers (e.g., Castellví et al., 2017; Nock et al., 2013), which identified a desire to die by suicide or thinking about suicide as a precursor to having the capability to die by suicide or planning a suicide attempt. It is worth noting that the question ascertaining whether participants thought about suicide in the present study included the qualifier that they *seriously* considered suicide in the last 12 months. Therefore, it is possible that Colorado adolescents think about suicide on different levels, ranging from more casual thoughts about suicide to more serious considerations, and their risk for attempting suicide multiple times only increases when that plan is coupled with seriously considering suicide. Additional research is necessary to further explore the predictive influence of suicidal ideations across its intensity range to best understand the role of suicidal ideations as a predictor of suicide attempts for Colorado adolescents.

Another pattern emerged regarding the rates by which participants in the present study endorsed engaging in NSSI over the last 12 months. Specifically, greater endorsement of NSSI

over the last 12 months appeared as a possible predictor of multiple suicide attempts in eight trees, but it was only identified as the most salient predictor of multiple suicide attempts in one tree—the tree exploring only distal predictors of suicide attempts compared to never attempting suicide in the 2019 dataset, but endorsement of NSSI in this model was only a salient predictor of multiple suicide attempts when intersecting with creating a plan for suicide. Across the remaining seven trees where NSSI appeared as a predictor of multiple suicide attempts, the predictor was only significant when interacting with and after other risk behaviors such as (1) creating a plan for suicide, smoking cigarettes on more days in the last month, and misusing prescription medications more times in the last month, (2) being physically forced into an unwanted sexual encounter, and (3) creating a plan for suicide, seriously considering suicide, and being physically forced into an unwanted sexual encounter, to name a few examples.

These findings highlight that endorsement of NSSI over the past 12 months was only a significant predictor of multiple suicide attempts when intersecting with other health risk behaviors and sociodemographic variables in the present sample. Additionally, this result contrasts previous research findings that engaging in self-injurious behaviors without the intention of dying is one of the most predictive risk factors for future suicide attempts (Edgcomb et al., 2020; WHO, 2023). The finding of the present highlights that greater nuisance may exist across the utilization of NSSI among Colorado adolescents as a coping skill that only becomes indicative of multiple suicide attempts in the presence of additional health-risk behaviors and sociodemographic variables.

In addition to the difference in the number of predictors of multiple suicide attempts identified in the classification trees using single suicide attempts and no suicide attempts as comparison groups discussed earlier, there was considerable divergence in the average accuracy

for each comparison group. Namely, the trees using single suicide attempts as the comparison group had an average accuracy rate of 59.45%, and the trees using never attempted suicide as the comparison group had an average accuracy rate of 94.31%. Although both accuracy rates are acceptable, the average accuracy rates for the classification trees using never attempting suicide as the comparison group performed substantially better, indicating that these models are statistically more likely to accurately predict suicide attempts compared to models using single suicide attempts as the comparison group. Alternatively, it possible that the difference in average accuracy ratings for each comparison was influenced by the average sample sizes for these groups. The average sample size for the trees using single suicide attempts as the comparison group was 2,115, whereas there was an average sample size of 19,366 for the trees using never attempting suicide as the comparison group. The accuracy of classification trees increases with sample size, supporting the possibility that the accuracy rates for the models using never attempting suicide as the comparison group is being artificially inflated (Morgan et al., 2003). To correct for this possibility, future research exploring the differences in predictors of multiple suicide attempts compared to both single suicide attempts and never attempting suicide could prioritize comparable sample sizes to draw more meaningful conclusions across the trees.

Because classification trees often consist of proximal predictors of the outcome variable (e.g., Edgcomb et al., 2021; Wallace et al., 2020), the present study explicitly explored three sets of predictors: all possible predictors of suicide, distal predictors only, and proximal predictors only to best capture the predictors of multiple suicide attempts among Colorado adolescents. The classification trees exploring predictors of multiple suicide attempts compared to individuals who attempted suicide once in the present study were often dominated by distal predictors of suicide that either did not appear or seldomly appeared in the trees with individuals who never

attempted suicide as the comparison group (e.g., sexual orientation, assigned sex, age, intersection of race ethnicity). Conversely, the trees using individuals who never attempted suicide as the comparison group included more proximal predictors of suicide that did not appear in the trees using the individuals attempting suicide once as the comparison group (e.g., 30-day electronic vapor product use, lifetime number of sexual partners, age at first sexual experience, 30-day number of alcohol binges).

These differences across the classification trees likely highlight the power of a previous suicide attempt in being able to predict a future suicide attempt. As stated earlier, the most predictive risk factor for future suicide attempts is previous self-injurious behaviors, both with and without the intention of dying (Edgcomb et al., 2020; WHO, 2023). Therefore, the general risk factors (e.g., engagement in NSSI, general and problematic substance use) that place an adolescent at risk for attempting suicide one time are likely to be similar to the general risk factors that place an adolescent at risk for attempting suicide multiple times. Without higher order risk factors such as psychiatric diagnoses, family history of mental illness, and incidents of stress, the proximal predictors of multiple suicide attempts were likely evenly shared across adolescents who attempted suicide once, causing the distal predictors to emerge in the models as risk factors for multiple suicide attempts (Okan İbiloğlu et al., 2016). To address this issue, future research should comprehensively capture both general and highly discerning risk factors of suicide attempts that are both proximal and distal to meaningfully draw conclusions about possible differences in the rate by which proximal and distal predictors of suicide appear in classification trees when altering the comparison group in the tree.

Despite seeing a greater number of distal predictors in the trees comparing individuals who attempt suicide multiple times to those who attempt suicide once and conducting

classification trees with only distal predictors included in the model, few intersections between different sociodemographic variables included in the present studies were identified as salient predictors of multiple suicide attempts. Namely, the variable intersecting participant race and ethnicity appeared in five trees, though this intersectional variable appeared at the terminal node or the last variable before the terminal node in a string of three to seven predictors in four of the five trees. This intersectional variable always appeared on the left side of the trees, indicating that a smaller percentage of the participants follow that predictive path toward the outcome variable. Outside of the intersectional variable addressing race and ethnicity, very few intersections of sociodemographic predictors appeared across the 20 interpreted trees. Figure 8 highlighted an intersection across participant race and ethnicity, sexual orientation, and age, and Figure 15 includes an intersection between participant race and ethnicity with participant age. In both cases, these intersectional variables also appear on the left side of the trees. Taken together, these findings highlight that although significant, the intersections of sociodemographic variables in these classification trees play minor roles in predicting multiple suicide attempts. It is also possible that the predictive value of more proximal variables (such as creating a plan for suicide and recent substance use) is overpowering the models and making it difficult for the salience of these intersectional variables to come through in the model. It would be beneficial for future researchers to create individual classification trees across different intersectional identities, similar to what was done in the present study for people with non-dominant transgender and sexual orientation identities, to accurately capture the predictors that place these individuals at greater risk for attempting suicide multiple times.

It is worth noting that multiple trees across both comparison groups (single suicide attempts and never attempting suicide) demonstrated moderate capability in explaining the

variance of the study sample while simultaneously displaying only marginal capabilities in explaining the variance in cross validation samples. In other words, these trees are effective in explaining the outcomes of the current sample but are only slightly better than chance in predicting the outcomes in new, comparable samples. For example, the 2019 tree investigating only the proximal predictors of multiple suicide attempts compared to never attempting suicide explained 6% of the variance in the sample but only 3% of the variance, on average, in the cross-validation samples. The 2019 tree investigating all predictors of multiple attempts compared to those who attempt suicide once explained 19% of the variance in the sample and 4% of the variance, on average, in the cross-validation samples. Both trees must be interpreted with caution because their ability to explain the variance in their sample is acceptable while the ability to explain the variance in cross-validation samples is only slightly better than chance

Additionally, the trees formed out of 2019 dataset consistently displayed the highest cross validation errors and confidence intervals compared to the trees from the 2015 and 2017 datasets within the same comparison subsets and predictor subsets. It is possible that the heterogeneity of the 2019 dataset was much higher than the heterogeneity in the 2015 and 2017 datasets, causing the classification trees to perform worse when trying to generalize to cross validated samples. The data for the 2019 Healthy Kids Colorado Survey were collected in different regions throughout the state of Colorado, including urban, suburban, and rural communities and spanned many of the major cities throughout the state (e.g., Denver, Colorado Springs, Fort Collins; CDPHE, 2020). Data within each region had the potential to be widely heterogenous depending on the school that was randomly selected to participate in the 2019 survey. Unfortunately, data at the school-level is not available for analyses to protect the anonymity of the students who participated in the study. Data collection would need to be replicated at the schools that

participated in the 2019 survey to extrapolate if the high cross validation errors in this dataset were due to heterogeneity at these schools or if another factor influenced these rates (e.g., changing demographics across the state as a whole at that time).

The second research aim of the present study was to investigate if the interacting and intersecting variables that were most salient in predicting multiple suicide attempts varied across each year of data collection. It was suspected that the predictor variables would change across cohorts as a product of (1) the longitudinal passing of time, (2) the salience of specific health risk behaviors at different times in society (e.g., increasing prevalence of vaping among adolescents; Boudi et al., 2019; CDC, 2014); and (3) increased use of smartphones and social media among adolescents (Twenge et al., 2018). In general, the predictors identified in the present study as indicative of multiple suicide attempts among Colorado adolescents were largely consistent across the years of collection with little to no discernable pattern over time. One exception was the emergence of select substance use variables as significant predictors of multiple suicide attempts in the 2019 classification trees that did not appear in the 2015 and 2017 trees.

The following substance use items emerged as significant predictors in the 2019 dataset: the number of days in the last month when participants drank alcohol, the number of times participants used cocaine in their lifetime, the number of times participants sniffed glue, breathed the contents of aerosol spray cans, or inhaled any paints or sprays to get high in their lifetime, and the number of days in the last month when participants engaged in an alcohol binge. The identification of these substance use predictors in the 2019 classification trees aligns with research that the intentional misuse of substances has increased among adolescents throughout the United States of America from 2000 to 2020 as measured by reports to poison centers across the nation (Hughes et al., 2023). Therefore, it is possible that the identification of these

predictors in the 2019 classification trees is a reflection of the changing landscape around substance misuse among adolescents in the United States.

It is difficult to collect rare outcome data, such as multiple suicide attempts, among distinct, non-dominant sociodemographic groups because these populations are smaller, making it difficult to conduct complex statistical analyses, such as classification trees (Balzer et al., 2016). The Healthy Kids Colorado Survey utilized in the present study provided an opportunity to explore this rare outcome data because of the size of the datasets. Therefore, the third research aim of the present study was to investigate if the predictors of multiple suicide attempts differed for individuals who identified as holding one or more non-dominate sociodemographic identity in the categories of transgender identity and sexual orientation compared to the predictors identified for all participants together. Out of the six trees that were attempted to address this research aim, only four were interpreted and the remaining two trees were dropped due to the trees being overfit. The remaining four trees were constructed with limited sample sizes compared to the sample sizes used to investigate all predictors of multiple suicide attempts using all participants. Because the samples were small, there was a higher likelihood that the tree parameters were unstable. This instability is best indicated by the cross-validation error confidence interval approaching one for some of these trees.

In the present sample, trees exploring predictors of multiple suicide attempts among participants with at least one non-dominant transgender or sexual orientation identity contained more substance use predictors than the trees predicting multiple suicide attempts for all participants. Four predictors addressing cigarette use and prescription misuse in the past month and lifetime heroin and cannabis use appeared in trees for all participants and those with one or more non-dominant transgender or sexual orientation identity. Conversely, the four predictors

addressing alcohol and electronic vapor product use in the last month, participant age at their first cannabis use, and lifetime methamphetamine use appeared in the trees for participants with one or more of the aforementioned non-dominant identities but did not appear in the trees for all participants. There was no substance use related predictors that appeared in the models for all participants but did not appear in the models for participants with non-dominant identities. This pattern suggests that substance use is an elevated risk factor for multiple suicide attempts among participants with one or more non-dominant transgender or sexual orientation identity.

Three additional predictors were identified as being significant predictors for multiple suicide attempts among all participants but did not appear in the trees for participants with non-dominant sexual orientation and transgender identities. Those variables included whether participants experienced an injury while attempting suicide in the last 12 months, assigned sex, and if participants could identify an adult in their life to whom they could go if they were in trouble. Each of these predictors appeared in the trees comparing multiple suicide attempts to single suicide attempts for all participants. Two of the three trees investigating multiple suicide attempts compared to single suicide attempts for participants with non-dominant identities were not interpreted because they were overfit. Therefore, it is possible that the aforementioned variables could have appeared in the non-dominant identity trees had they not overfit. Replication with larger sample sizes for individuals who have one or more non-dominant sexual orientation or transgender identity is necessary to explore if this pattern is generalized beyond the present sample.

**Limitations**

While the atheoretical and exploratory nature of classification trees was essential in the present study for exploring the possible predictors of multiple suicide attempts in Colorado

adolescents given the dearth of research in this area, this approach has limited generalizable utility (Jaeger, & Halliday, 1998). By its nature, exploratory research only explores the possible relations between variables without a theory to support the potential direction and strength of those relations (Gonzalez, 2021; Leclerc, 2009; Ware et al., 2022). Engaging in supervised machine learning as well as utilizing cross validation samples helped to increase the generalizability of the present study. Despite these efforts, additional research must be conducted, replicating the findings of the present study to either confirm or refute these findings both within similar and highly discrepant adolescent samples before the findings of the present study can be considered robust and generalizable (Hellemann et al., 2009; Wallace et al., 2020).

The cohort sequential design (sometimes also referred to as an accelerated longitudinal design) of the present study allowed for the critical examination of the ways that risk factors for multiple suicide attempts changed over the four years of data collection (Prinzie & Onghena, 2014). This research design is particularly beneficial for research with adolescents given the rate at which their cognitive, affective, and social development is occurring compared to their development throughout adulthood because a cohort sequential design captures quickly changing trends (Crone & Dahl, 2012). While beneficial in some ways, this cohort sequential approach offered limited utility in exploring the possible ways that risk factors can compound over time, putting adolescents at greater risk for multiple suicide attempts in the future (e.g., simultaneously navigating the illness within one's family, being diagnosed with a severe and persistent mental illness, and experiencing a global pandemic; Abascal-Peiró et al., 2023). In the future, longitudinal research may need to be conducted to capture the effect of compounding risk factors on the likelihood of adolescents attempting suicide multiple times.

It is imperative to understand that the variables identified in the classification trees did not represent causal relations between these variables and multiple suicide attempts. Rather, these predictor variables had the strongest correlation with multiple suicide attempts, implying salient etiological and epidemiological factors of interest. Therefore, the generalizability of these classification trees outside of the present study are limited and should be undertaken with caution. For example, the predictors of multiple suicide attempts in this sample were highly restricted to only the questions asked in the Healthy Kids Colorado Surveys during the 2015, 2017, and 2019 data collection years. The questions in the surveys do not fully capture all risk factors for multiple suicide attempts because the survey was intended to identify the social, emotional, and physical health of Colorado adolescents at school and home, including but not limited to suicide (CDPHE, 2020). Therefore, the intersecting and interacting variables identified as risk factors for multiple suicide attempts in the present study may be unique to the present sample. It would be beneficial to replicate the machine learning analyses utilized in the present study with a broader and larger adolescent sample and to include a larger number of variables identified as risk factors for suicide to determine if the results of the present study can be generalized beyond the present sample.

While the Healthy Kids Colorado Survey served as a helpful snapshot into the lives of Colorado adolescents, the limited range of survey items could possibly be influencing the relatively low predictive ability of the CTs. The purpose of the Healthy Kids Colorado Survey is to ascertain the health and safety of Colorado adolescents broadly, including, but not limited to, substance use, mental health variables, and sexual behaviors (CDPHE, 2020). While the focus of the present study was on risk factors of multiple suicide attempts among adolescents, this same focus is not shared by the researchers and developers of the Health Kids Colorado Survey.

Therefore, a number of predictors of multiple suicide attempts identified by other researchers, such as psychotic disorders (Stoliker, 2021), PTSD (Park et al., 2020), mood disorders (Pennel et al., 2018), personality disorders (Sinclair et al., 2016), a history of childhood trauma (Cankaya et al., 2011), substance use (Icick et al., 2018), family history of mental illness (Icick et al., 2019), and stressful life events (Okan İbiloğlu et al., 2016), were not included in the survey because they were beyond the scope of the survey's intended purpose. To truly capture the most predictive variables of multiple suicide attempts among Colorado adolescents, additional research is needed using questions and surveys specifically curated for the prediction of suicide.

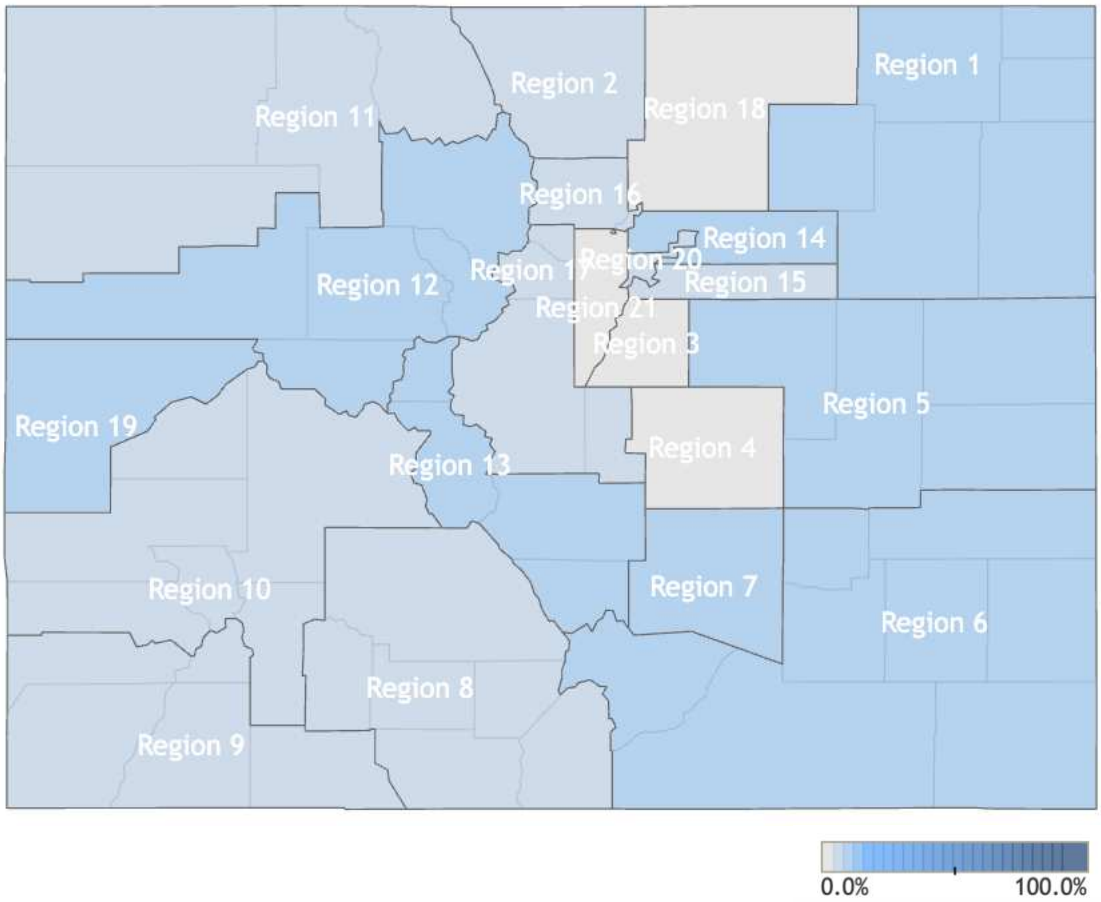
**Conclusions**

The results of this study are a crucial first step in better identifying adolescents who could be at risk for attempting suicide multiple times based on the intersecting sociodemographic and interacting risk behaviors that were identified as consistent with multiple suicide attempts. By more accurately identifying adolescents at risk for attempting suicide multiple times, efforts can be focused on developing optimized prevention plans aimed at reducing the number of adolescents who will go on to attempt suicide multiple times by identifying adolescents who endorse two or more risk factors for multiple suicide attempts that appear in the same classification branch identified in this study (e.g., individuals who endorse smoking cigarettes often in addition to using heroin in their lifetime). These prevention plans could be used to increase community awareness about adolescent suicide risk and decrease the taboo of discussing suicide (WHO, 2023). In conclusion, machine learning methodologies are an effective way to identify and subsequently reduce the rates of multiple suicide attempts among adolescents in Colorado communities.

# APPENDIX

**Figure 1**

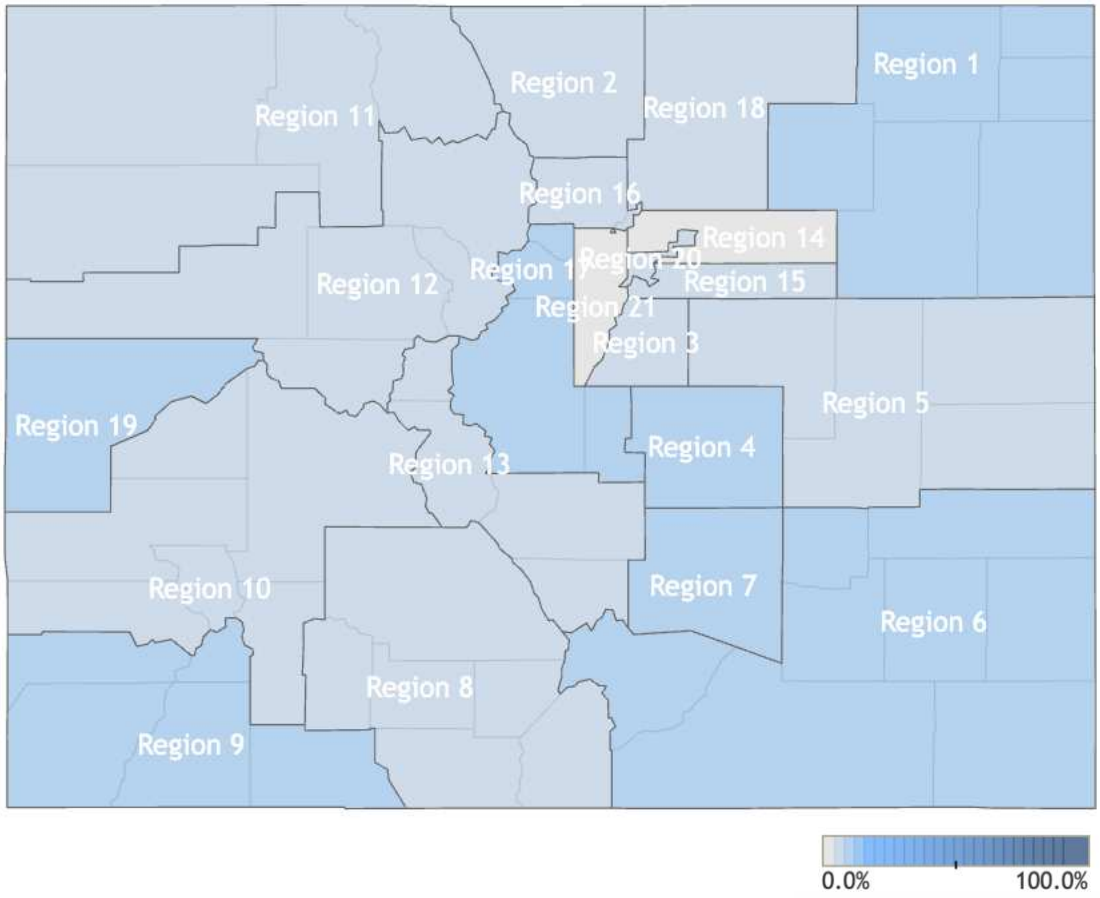
*Map Depicting the Dispersion of Participation in the 2015 Healthy Kids Colorado Survey*




*Note.* To protect the anonymity of participants, all data for the Healthy Kids Colorado Survey is aggregated to the region in which the data was collected. The dispersion of participation in the 2015 Heathy Kids Colorado Survey based on the number of participants who attempted suicide one or more times in the last 12 months. Regions that are grey represent those where no schools participated in the study for that year of data collection. Darker blue regions represent a higher percentage of participants in that region who endorsed attempting suicide one or more times in the last 12 months.

**Figure 2**

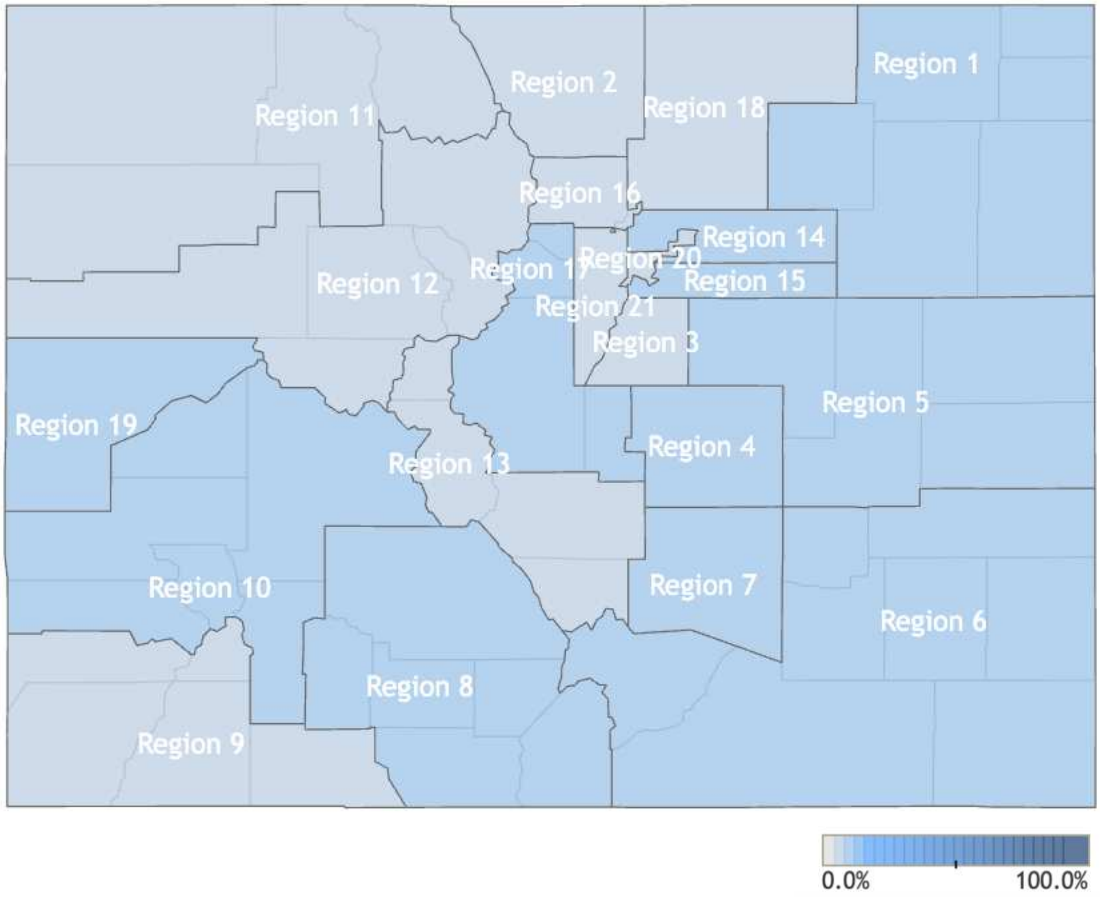
*Map Depicting the Dispersion of Participation in the 2017 Healthy Kids Colorado Survey*




*Note.* To protect the anonymity of participants, all data for the Healthy Kids Colorado Survey is aggregated to the region in which the data was collected. The dispersion of participation in the 2017 Heathy Kids Colorado Survey based on the number of participants who attempted suicide one or more times in the last 12 months. Regions that are grey represent those where no schools participated in the study for that year of data collection. Darker blue regions represent a higher percentage of participants in that region who endorsed attempting suicide one or more times in the last 12 months.

**Figure 3**

*Map Depicting the Dispersion of Participation in the 2019 Healthy Kids Colorado Survey*




*Note.* To protect the anonymity of participants, all data for the Healthy Kids Colorado Survey is aggregated to the region in which the data was collected. The dispersion of participation in the 2019 Heathy Kids Colorado Survey based on the number of participants who attempted suicide one or more times in the last 12 months. Regions that are grey represent those where no schools participated in the study for that year of data collection. Darker blue regions represent a higher percentage of participants in that region who endorsed attempting suicide one or more times in the last 12 months.

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