

EVALUATING THE CO-OCCURRENCE AND EXCHANGEABILITY OF ADVERSE
CHILDHOOD EXPERIENCES IN 21 STATES

By Jose Angel Olais

A Thesis

Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Arts
in Psychological Sciences

Northern Arizona University

December 2022

Approved:

Steven D. Barger, Ph.D., Chair

Eylin Palamaro-Munsell, Ph.D.

Robert Wickham, Ph.D.

ABSTRACT

EVALUATING THE CO-OCCURRENCE AND EXCHANGEABILITY OF ADVERSE CHILDHOOD EXPERIENCES IN 21 STATES

BY JOSE ANGEL OLAIS

Smoking is the leading cause of preventable disease, disability, and death in the US. There is strong evidence that current smoking is associated with adverse childhood experiences (ACEs), traumatic events that occur in childhood. This association is observed when comparing smoking prevalence across a cumulative exposure variable representing the number of ACEs experienced. However, no research to date has described specific ACE exposures, both individually and in combination, within a given cumulative count of adversities. Additionally, there is a recognized but largely untested assumption that individual ACEs (and ACE exposure categories) are equally prognostic for given health outcomes. Evaluating this assumption requires partitioning individual ACE exposures within each cumulative risk category. The first objective of this study was to partition the composition of individual ACE exposures within cumulative risk categories. The second goal was to evaluate the exchangeability assumption of the cumulative categorical risk model by comparing the individual ACE exposures that comprise a singleton and pair ACE category. In a national sample of 115,230 adults across 21 states, divorce, verbal abuse and physical abuse were the most common elements of singleton ACE exposures, and heterogeneity was observed for smoking prevalence, where persons experiencing divorce (18.7%) had substantially higher smoking prevalence than persons experiencing verbal abuse (11.5%) despite exposure to a single adversity. No heterogeneity was observed among the top three pairwise ACE clusters. This study provides evidence that individual ACE exposures are not exchangeable in terms of their association with smoking. The

approach to partitioning ACE clustering described here provides a foundation for further evaluation of ACE exchangeability within higher cumulative exposure categories and among different health outcomes.

Keywords: Adverse childhood experiences, current smoking, education level, trauma, ACE measurement, ACE co-occurrence

Table of Contents

Abstract	ii
Table of Contents	iv
List of Tables	v
Dedications	vi
Introduction	7
Purpose	16
Methods	17
Results	20
Discussion	22
References	29

List of Tables

Table 1 Participant Demographics & Cumulative Exposure to ACEs	34
Table 2 Weighted Frequencies of Individual ACEs in 2019 BRFSS	36
Table 3 Percentages of ACE Counts & Top Five Most Commonly Occurring ACEs	38
Table 4 Incidence Rate Ratios for Regressions of Current Smoking on ACEs	40
Table 5 Smoking Proportions by ACE at Different ACE Exposures	41
Table 6 Heterogeneity Tests for Single & Double ACEs on Current Smoking	42

Dedication

As a first-generation student, the journey through graduate school is an exciting and nerve-wracking feat. I would like to thank my family for their unconditional support and sacrifices. I would also like to thank my mentors, for their patience, ambition, and mission to guide new researchers into the scientific field.

Introduction

Adverse childhood experiences (ACEs), defined as potentially traumatic events that occur in childhood (Centers for Disease & Control [CDC], 2021), are linked to chronic disease, poor mental health, and other negative outcomes in adulthood (Anda et al., 1999; Chapman et al., 2004; Crouch et al., 2020; Felitti et al., 1998; Ford et al., 2016). For example, greater ACE exposure is linked to greater risk of obesity and smoking (Anda et al., 1999; Bellis et al., 2014a), higher levels of depression and other adverse mental health conditions (Chapman et al., 2004; Edwards et al., 2003; Tsehay et al., 2020), and more prevalent chronic disease (Bellis, 2014b; Campbell et al., 2016; Ford et al., 2016; Ramiro et al., 2010; Ye & Reyes-Salvail, 2014). These patterns have been generally confirmed in studies comprising over a quarter million people (Merrick et al., 2018). Thus, there is substantial evidence that these adverse experiences are linked to negative adult health outcomes.

Our understanding of the burden of these experiences can be improved by addressing two key questions regarding ACEs measurement and exposure definitions. First, a consistent observation is that ACEs occur in clusters, with 38.1% of the population reporting two or more ACEs (Merrick et al., 2018). Given the high prevalence of clustering (see also Dube et al., 2003), a number of studies have described the co-occurrence of ACEs (Dong et al., 2004; Downey et al., 2017; Dube et al., 2003; Kim et al., 2020; Lacey & Minnis, 2020). However, these are generally limited to pairwise descriptions. The only report to date examining larger ACE clusters only described aggregated comorbidity, i.e., the percentage of respondents experiencing one specific ACE who experienced an additional two more ACEs (Ramiro et al., 2010). Thus, little is known about the form of ACE co-occurrence despite its ubiquity in the population and the health disadvantages associated with multiple ACE exposures. The first goal

of the present study is to describe the co-occurrence of ACE clusters, including clusters up to four ACEs, in a large, population-based U.S. adult sample. Ultimately, characterizing the prevalence and form of higher-level ACE clustering can inform public health efforts by providing a foundation for comparing comorbid ACEs across time and across social groups (e.g., Merrick et al., 2018), by revealing observed patterns of ACE co-occurrence beyond that provided by extant literature, and by providing precise ACE targets for prevention.

The second question regards the exchangeability of ACEs. The association of ACEs with adult health outcomes is typically evaluated by comparing health outcomes as a function of a simple exposure of the number of ACEs experienced. For example, persons endorsing one adverse experience (versus zero) are more likely to have poorer mental health in adulthood (Edwards et al., 2003), be diagnosed with chronic conditions such as diabetes, stroke, or cancer (Slack et al., 2017) and to be a current smoker (Campbell et al., 2016). As noted elsewhere (Evans et al., 2013; Lacey & Minnis, 2020; Olofson, 2018), the count approach presumes each ACE domain is equivalent or exchangeable. In other words, reporting one ACE conveys the same health risk regardless of whether that ACE is parental divorce or sexual abuse. Evaluating this assumption was the second goal of the present study; to examine whether singleton and pairwise ACEs are exchangeable in terms of their association with one potent health risk behavior, cigarette smoking.

The proposed study is a secondary analysis of the 2019 U.S. Behavioral Risk Factor Surveillance System (BRFSS) survey (CDC, 2020a). The BRFSS included the ACE items from the original Felitti et al. (1998) study which encompassed childhood emotional, physical, and sexual abuse in addition to intimate partner violence (among parents/caregivers), substance abuse, household mental illness, divorce, and parental incarceration. In 2019, the ACE module

was fielded by 21 U.S. states encompassing over 100,000 adult respondents. These BRFSS data provide a robust opportunity to 1) characterize ACE clustering and 2) evaluate the exchangeability or equivalence of individual adverse childhood experiences.

Below is a more detailed review of the association of ACEs with adverse health outcomes, prior evaluations of ACE clustering, and a review of operational definitions of ACE exposure. The operational definitions review focuses on cumulative ACE exposure models, particularly comparisons that address the exchangeability of individual ACEs. The review ends with the health impact of cigarette smoking and its utility for evaluating the exchangeability of individual ACE exposures.

Adverse Childhood Experiences Overview

Adverse childhood experiences (ACEs) are traumatic events linked to negative health outcomes in adulthood (CDC, 2021). The study of ACEs began with a seminal report that explored the long-term relationship between adverse childhood experiences and adult health among persons enrolled at the Kaiser Permanente clinic in San Diego, CA (Felitti et al., 1998). That study assessed the presence or absence of seven domains of childhood adverse experiences: psychological, physical, or sexual abuse; violence against the mother; living with household members who were a) substance abusers, b) mentally ill or suicidal, or c) ever imprisoned. These adversities were scored in a binary fashion and summed to create an index of ACE exposure. They found adults with a higher number of reported ACEs had a significantly higher prevalence of smoking, severe obesity, physical inactivity, depressed mood, and problem drinking relative to those with fewer or zero reported ACEs (Felitti et al., 1998).

Subsequent literature has generally confirmed and expanded the initial findings regarding ACE exposure. A positive association between ACE exposure and greater health risk

has been observed within single U.S. states (Downey et al., 2017; Ye & Reyes-Salvail, 2014) and in pooled analysis of multiple states (Barile et al., 2015; Loudermilk et al., 2018). Other research aggregating multiple years of national data across multiple states also showed greater health risk associated with greater ACE exposure (Merrick et al., 2018). Further, cumulative exposure to ACEs is associated with psychological and medical morbidity in populations outside the United States, including Asia (Chang et al., 2019), Europe (Danese et al., 2009; Ford et. al, 2016), and the Middle East (Almuneef et al., 2014).

Adverse Childhood Experiences and Morbidity

Cumulative ACE exposure is associated with a wide variety of health conditions, with some of the strongest linear associations observed for well-being outcomes such as poor mental health and poor self-rated health. For example, in a representative sample of a single U.S. state, individuals with one or more ACES had four times higher odds of lifetime depression adjusted odds ratio (AOR = 4.0, 95% CI [3.0-5.5]) and this was linear across one (AOR = 2.0, 95% CI [1.4-.3.0]), two (AOR = 4.2, 95% CI [2.8-6.3]), three (AOR = 4.6, 95% CI [2.9-7.3]) and four ACE exposures (AOR = 6.5, 95% CI [3.9-10.9]), respectively (Ye & Reyes-Salvail, 2014). Self-rated health is a marker of health-related quality of life and is also lower for persons with greater ACEs exposure. The percentage of persons reporting fair or poor health across 0, 1-3, 4-6 and 7-9 ACE categories was 11%, 13%, 20%, and 28%, respectively (Gilbert et al., 2015). ACE exposure is also associated with prevalent chronic disease (Campbell et al., 2016) including heart disease, stroke, cancer, lung disease, and diabetes. However, these associations have been found to be smaller in magnitude and the relationship for several of these outcomes appears to be non-linear (Bellis et al., 2014a; Campbell et al., 2016; Downey et al., 2017). In sum, there is

extensive literature that encompassed hundreds of thousands of participants showing the health burden of cumulative ACE exposure across diverse populations.

ACE Co-occurrence

As noted above, greater ACE exposure is associated with a number of adverse health outcomes in adulthood. Because of the robust association of health outcomes with cumulative ACEs exposure, it is useful to understand both the prevalence and form of ACE co-occurrence. That is, what percentage of persons report more than one ACE, and among those persons what are the most common sets of co-occurring ACEs at various levels of cumulative exposure (i.e., two, three, or four ACEs)? In the original Kaiser study, 67% of 8,613 adults reported at least one ACE. Among those with at least one ACE, at least 56% reported an additional ACE (Dube et al., 2003). Similar ACE co-occurrence has been reported elsewhere. Using nationally representative U.S. data, Merrick et al. (2018) found that among 214,157 adults, 38.5% experienced no ACEs and 62% reported at least one ACE, and 38% reported two or more ACEs. In that largest U.S. study to date, the most commonly reported individual ACEs were household substance abuse (28%) and parental separation or divorce (27%) (Merrick et al., 2018). In sum, both ACE exposure and co-occurrence of ACE exposures are prevalent in the population.

Despite the generally high prevalence of co-occurring ACEs, this co-occurrence (also known as comorbidity) has only been superficially examined (Dube et al., 2003; Ramiro et al., 2010). For example, it has been noted that 31% of persons reporting alcohol abuse in the home also reported psychological abuse, and half of that group reported an additional but unspecified ACE (Ramiro et al., 2010). Other studies provided similarly nonspecific clustering descriptions at the level of two or more ACE exposures. For example, among men who experienced physical abuse, 10.8% also reported sexual abuse and/or maternal battering (Edwards et al., 2003) but the

authors did not report the breakdown of the latter two counts. Thus, earlier literature alluded to ACE comorbidity but did not clearly identify the form and prevalence of ACE co-occurrence beyond pairwise exposure. Characterization of ACE clustering can advance our understanding of the burden of different forms of adversity and provide a foundation for comparing adversity across different groups.

To provide a more detailed characterization of ACE co-occurrence, the present study described not only the prevalence of cumulative ACE exposure (i.e., zero, one, two, three, and four) but also the *composition* of singleton and co-occurring ACE exposure in a nationally representative US sample. The study characterized the most common singleton ACEs, as well as the most common sets of ACEs that comprised double, triple, and quadruple cumulative ACE exposures. It was expected that there would be a large number of relatively uncommon combinations, so estimates were limited to combinations representing at least 3-5% of cases within a given ACE exposure category.

ACE Measurement

ACE exposure is most commonly operationalized by a simple sum of the number of ACEs experienced (Evans et al., 2013; Felitti et al., 1998; LaNoue et al., 2020). For instance, if there are nine ACE indicators, these are scored in a binary fashion (present/absent) and summed to produce categories such as zero, one, two, three or four or more ACEs. Typically, ACEs of four or higher are collapsed to have sufficient cell sizes for estimation. This categorical approach, called a *categorical cumulative risk model*, does not assume a linear association with summary ACE scores (LaNoue et al., 2020). This is the most common approach to operationalizing ACE exposure and as noted above, these categories are strongly associated with medical and psychological morbidity in adult populations. Although there are other

approaches to classifying ACE exposure (e.g., latent class models; (Lacey & Minnis, 2020)), we only evaluated the cumulative exposure method because 1) it is the most common approach in the literature (LaNoue et al., 2020); and 2) it contains a recognized but largely untested assumption that individual ACEs (and ACE exposure categories) are equally prognostic for a given health outcome (Evans et al., 2013; Lacey & Minnis, 2020).

Are Individual ACEs Exchangeable in Cumulative Risk Formulations?

A key question regarding the cumulative exposure approach is whether reporting one ACE conveys the same health risk regardless of whether that ACE is parental divorce, parental incarceration or having experienced sexual abuse (cf. Evans et al., 2013; Lacey et al., 2020; LaNoue et al., 2020). That is, given that exposure comparisons are based on a cumulative count of *any* ACE exposure(s), it is assumed that any form of that accumulation is equally predictive of a given health outcome. This exchangeability assumption has not been directly tested; however, several studies indirectly show that the strength of association across individual ACE exposures is unequal, warranting further examination of this assumption.

Campbell et al. (2016) provided individual regression coefficients for each of eight ACEs across several different health outcomes. The predictive strength for individual ACE regression coefficients varied within health outcomes, potentially suggesting a lack of exchangeability. For instance, smoking was statistically linked to sexual abuse, verbal abuse, substance abuse, and divorce but not to physical abuse, mental illness, violence in the home or parental incarceration. Thus, some ACE exposures were statistically associated with an outcome whereas others were not.

Although it may be tempting to conclude that ACE exposures are not exchangeable based upon differential patterns of statistical significance, this is a misconception (Gelman &

Stern, 2006). Instead, individual coefficients must be compared to each other (rather than the null) to determine if coefficients are equivalent, i.e., if the ACE exposures are exchangeable. I used heterogeneity tests to directly compare individual ACE coefficients to each other (Kaufman & MacLehose, 2013), and found evidence that ACE exposures in Campbell et al. (2016) were not exchangeable. For smoking the coefficient for sex abuse (AOR: 1.26, 95% CI [1.01 1.56]) was significantly higher than the coefficient for mental illness (AOR: 0.85 95% CI [0.71 1.02]) (ratio of estimates = 1.48, 95% CI [1.12, 1.97]; $z = 2.73$, $p = 0.006$). In addition, the coefficient for parental incarceration was larger than the coefficient for mental illness in the home (ratio of estimates = 1.38, 95% CI [1.02, 1.86]; $z = 2.10$, $p = 0.04$) despite neither ACE being statistically associated with smoking.

Thus, there was evidence that individual ACEs are not equivalently predictive of certain adult health outcomes, even though extant literature has yet to explicitly evaluate the exchangeability assumption as described above. The present study built upon this evidence to evaluate the exchangeability of individual singleton ACE exposures relative to the overall coefficient for any single ACE. The focal evaluation compared the regression coefficient for specific singleton ACEs (i.e., parental divorce; physical abuse, etc.) within a cumulative exposure of 1 ACE and for the regression coefficients for the pairwise ACEs (i.e., co-occurring divorce/physical abuse vs. sexual abuse/physical abuse) within a cumulative exposure of two ACEs. This directly tested whether individual-level ACEs were equally predictive relative to the more generic yet widely utilized one and two category summary ACE exposure scores. For these comparisons we used current cigarette smoking as the outcome measure. We took this approach because the theory regarding ACEs presumes a general rather than exposure-specific influence of ACE exposures (Felitti et al. 1998) and other data driven approaches (i.e., latent

class analysis) are insufficient to explore this exchangeability assumption because the obtained classes are not mutually exclusive or discrete (Barboza, 2018). Thus, similar to ACE counts, these approaches do not identify unique ACE patterning (Lacey & Minnis, 2020).

Smoking as a Vehicle to Examine Exchangeability of ACE Exposures.

Smoking is the leading cause of preventable disease, disability, and death in the US, with an estimated 34.1 million adults in the United States being current smokers (CDC, 2020b). Smoking increases the likelihood of chronic diseases such as cancer, cardiac, and pulmonary diseases (CDC, 2010) and is the cause of approximately one in five deaths in the U.S. (CDC, 2020c). Thus, current smoking represents a potent modifiable health risk with substantial ecological relevance, and therefore provides a meaningful context for testing the exchangeability assumption.

Current Smoking and ACEs

As with many other outcomes, greater ACE exposure is associated with higher smoking prevalence. In representative data from five U.S. states in 2011 ($N = 48,526$), smoking prevalence was 10.7% for persons with no ACEs, 17.9% for persons with one ACE ($AOR: 1.61$ $95\% CI: 1.36, 1.91$) and was 21%, 24%, and 34% among those with two, three or four or more ACEs, respectively (Campbell et al., 2016). A similar pattern was observed in a single state in the 2012 BRFSS, where smoking prevalence was 11% for those with zero ACEs and 16% for persons with one ACE (Downey et al., 2017). Higher odds of smoking for one vs. zero ACEs was observed in a probability sample of almost 6,000 adults in Hawaii, but specific smoking prevalence was not reported (Ye & Reyes-Salvail, 2014). These studies show that smoking prevalence is strongly associated with ACEs, and importantly, that there is a large and reliable difference in smoking prevalence across zero vs. one ACE and zero vs. two ACEs. This gradient

at the lower end of ACE exposure provided perhaps the most sensitive context to evaluate the exchangeability of different types of ACEs among persons reporting one ACE. Because of this strong gradient and because of the potency of smoking as a health risk, the present study examined current smoking prevalence to evaluate exchangeability of individual ACE exposures.

Education, Smoking and ACEs

Socioeconomic status (SES) indicators such as education are associated with both ACE exposure (Giano et al., 2020) and smoking (Nelson et al., 2003). For example, adults with a high school or less education report higher prevalence of one or more ACEs (61.4%) than adults with some college (59.2%) and persons with a college education or higher (53.6%) (Ye & Reyes-Salvail, 2014). This gradient of ACE exposure has also been reported by others (Font & Maguire-Jack, 2016; Ford et al., 2011). Along with stratifying ACE exposure, education also is strongly related to smoking - smoking prevalence is 29.8% among persons with less than a high school education and 12.8% among persons with a college degree or higher (Nelson et al., 2003). Given the strong potential for confounding by education it is included as a covariate in sensitivity analyses for the regression models and the heterogeneity tests.

Purpose

The first goal of the present study is to describe the co-occurrence of ACE clusters, including clusters up to four co-occurring ACEs, in a large, population-based U.S. adult sample. This was accomplished with a creative classification approach described by Long (2009) (see below). The second goal was to evaluate the exchangeability assumption of the cumulative categorical risk model by comparing the individual and multiple ACE exposures that comprise singleton and pairwise ACE exposures. The assumption was evaluated by comparing the regression coefficients of the individual and pairwise ACE exposures to each other. This

formally evaluated the previously untested assumption whether individual ACEs (and ACE exposure categories) were equally prognostic for a given health outcome, in this case smoking prevalence.

Methods

Data source

This study used data from the 2019 BRFSS. The BRFSS is a nationally representative telephone survey conducted annually by the Centers for Disease and Control and Prevention (CDC) that collects information on health-related risks, chronic disease, and use of preventive services from non-institutionalized adults (18 years of older) in the U.S. (CDC, 2020a). BRFSS is composed of three questionnaires; 1) a core component that all states use, 2) optional BRFSS modules that states choose to incorporate in their data collection, and 3) state added questions. BRFSS data collection uses stratification, where high-density and medium density telephone numbers are used to obtain a probability sample of all households. Further, data weighting is used, which helps make sample data representative of the population (CDC, 2020a). We used the 21 states who fielded the optional ACE module in the 2019 BRFSS. This provided an analytic sample size of approximately 115,000, which in turn provided sufficient cell sizes for examining individual-level ACE exposures.

ACE Operationalization

Adverse childhood experiences were measured using the ACE module based on the original ACE study (Felitti et al., 1998). This module included items regarding childhood emotional, physical, and sexual abuse in addition to household intimate partner violence (referred to as HIPV from here onward), substance abuse (alcohol; other drug use), household mental illness (referred to as HMI from here onward), divorce in the household (referred to

divorce from here onward), and household parental incarceration (HPI). Emotional abuse is assessed by a question regarding being sworn at or put down, so we subsequently refer to this adversity as verbal abuse. Having a parent or adult in the household who was a problem alcohol user is referred to as “problem drinker” from here onward. It is distinct from another question asking about illicit use of drugs.

The 11 ACE items were coded into 11 binary variables. Four of these are naturally binary (HPI, problem drinker, illicit drug use, depressed or suicidal family member), where respondents noted whether the ACE exposure was present or absent. Six ACE items included a frequency component with response options such as *never*, *once*, or *more than once*. As is common practice (Downy et al., 2017; Slack et al., 2017), *once* and *more than once* were coded as present to create a binary exposure. The parental divorce item included the response option *parent not married* and that response was coded as not divorced. Refusals to answer or “don’t know/not sure” responses were coded as missing. ACE exposure was defined as a summary of these 11 binary items, with values ranging from 0-11. Participants were only included if they had valid values for all ACE items (Ford et al., 2014).

Current Smoking Status

Current smokers were defined as those who have smoked at least 100 cigarettes in their lifetime and who reported currently smoking every day or some days (CDC, 1994). Thus, former smokers were grouped with never smokers.

Education Level

Education level was categorized into four levels: less than high school, high school diploma or GED, some college, and college graduate or more. In sensitivity analyses education was entered as three indicator variables with less than high school as the referent.

Analytic approach

To characterize ACE co-occurrence, we used a simple, yet elegant approach described by Long (2009). This approach multiplied each of the 11 binary items by values increasing in orders of magnitude. For instance, the binary HMI variable (representing individuals who lived with someone with mental health problems) remained coded as 0/1, but the binary problem drinker variable was multiplied by 10, the HIPV variable by 100, the divorce variable by 1000, and so on through the list of items. The sum of these 11 transformed items creates a value corresponding to each unique observed ACE combination. For instance, if the three most common pairwise ACEs are 00011, 01010, 00110 then based on our binary reference we can see that these two-ACE combinations reflect co-occurrence of HMI and problem drinker (“1” and “10”), and divorce and problem drinker (“1000” and “10”), and problem drinker and HIPV (“10” and “100”), respectively. We present observed combinations within the first four cumulative sum categories, thus providing a clear description of the co-occurrence of ACE exposures within different counts of the *number* of reported ACEs.

We tested ACE exchangeability by statistically comparing regression coefficients from one singleton ACE with the regression coefficient of another singleton ACE, generated from regression models predicting current smoking. We used a general linear model with a Poisson family and log link to obtain the regression coefficients and confidence intervals that were used in the heterogeneity test. This approach is preferable to logistic regression with odds ratios because odds ratios overestimate the association when outcomes are common (> 10%) and the modified Poisson provides rate ratios which are more easily interpreted relative to odds ratios (Zou, 2004).

The absence of differences between individual coefficients supports the exchangeability assumption of the cumulative categorical risk model, i.e., that those ACE exposures have a statistically equivalent association with smoking. Conversely, statistical differences between coefficients provide evidence the exchangeability assumption is violated, i.e., some ACE exposures are more strongly related to smoking than others. We tested this assumption for the top three singleton ACEs and top three co-occurring ACE pairs generated from the descriptive component of the study. Each of those coefficients were tested against one another using a Wald statistic for the difference between coefficients (Kaufman & MacLehose, 2013). We conducted this analysis twice, one with just the ACE exposure in the model and again with a model that included education as a covariate. The latter provided an estimate of the sensitivity of the relationship between ACEs and current smoking while statistically controlling for this SES indicator, which is a potent correlate of both ACE exposure (Ford et al., 2011; Ye & Reyes-Salvail, 2014) and smoking (Cornelius et al., 2020).

Results

Participant demographics are in Table 1. A slight majority of participants were female (51.9%). Approximately 72.4% were White, 12.2% were Black/African American, and 9.8% Hispanic/Latinx. Most of the sample were married (51.5%) and 83.2% identified as never/former smokers and 16.8% were current smokers. The prevalence of individual ACE exposures are presented in Table 2. In terms of cumulative exposure, 35.4% of adults reported zero ACEs, 22.7% reported one ACE, 13.0% reported two ACEs, 8.7% reported three ACEs, 6.5% reported four ACEs, and 13.7% reported five or more ACEs (Table 3). These are in line with other national estimates (Merrick et al., 2018).

Decomposing Cumulative ACE Exposure

The top three singleton ACEs were divorce, verbal abuse, and physical abuse (Table 3). The top three ACE pairs were verbal abuse and physical abuse, verbal abuse and divorce, and problem drinker and verbal abuse. Weighted percentages of these ACE elements are presented in Table 3. Within the 22.7% of adults who reported only one ACE, a full 7.3% of the population reported divorce as their only ACE, 5.6% reported verbal abuse as their only ACE and 3.2% reported physical abuse as their only ACE. Among adults who reported two ACEs, 1.9% reported physical abuse and verbal abuse, 1.5% reported verbal abuse and divorce, and 0.9% reported problem drinker and verbal abuse. Additional clustering for persons reporting three and four ACEs are provided in Table 3. As expected, the percentage of the population experiencing these higher-order clusters is substantially smaller. For comparison the fourth and fifth most common exposures within each cumulative exposure category are provided in Table 3.

Association of Cumulative ACE Exposure and Smoking Prevalence

Before evaluating the exchangeability of the individual coefficients within cumulative ACE exposures, we evaluated the association of smoking with one and two cumulative ACE exposures separately. Adjusted for education, adults who reported any single ACE were 42% more likely to be current smokers than adults with zero ACEs, prevalence ratio (PR) = 1.42 (95% CI [1.31, 1.53]). Smoking prevalence was 14.2% (95% CI [13.1, 15.3]) for one ACE and 10.2% (95% CI [9.7, 10.7]) for zero ACEs in the adjusted model. Adults reporting two ACEs were 70% more likely to be a current smoker than adults with zero ACEs (PR = 1.70; 95% CI [1.57, 1.85]). Smoking prevalence was 17.3% (95% CI [6.2, 18.4]) within the two ACE exposure groups (Table 4).

Association of Specific Singleton and Pairwise ACE Elements with Smoking

All three of the top singleton ACEs were associated with higher smoking prevalence relative to zero ACEs. Prevalence ratios for the specific singleton ACE exposures, both unadjusted and adjusted for education, are presented in Table 4. Smoking prevalence among persons reporting divorce, verbal abuse and physical abuse was 16.9%, 12.5%, and 13.7% respectively (Table 5).

Similarly, all of the top three most common ACE pairs were associated with higher smoking relative to zero ACEs and these associations also persisted after adjustment for education (Table 4). Adjusted smoking prevalence was 16.5% for persons reporting verbal and physical abuse, 19.5% for persons reporting verbal abuse and divorce, and 16.9% for persons reporting verbal abuse and problem drinker (Table 5).

Exchangeability of Individual ACE Components

The prevalence ratios for the three most common single and double ACE compositions were compared to each other to determine whether the individual ACE components were exchangeable. Among the unadjusted singleton ACE coefficients, two of the three pairwise comparisons indicated heterogeneity. The ratio of coefficients comparing divorce and verbal abuse (ratio = 1.63; 95% CI [1.37, 1.94], $z = 5.43$, $p < .001$) and divorce and physical abuse (ratio = 1.32, 95% CI [1.09, 1.60], $z = 2.81$, $p = .004$) were different from each other but verbal abuse and physical abuse (ratio = 0.81, 95% CI [0.66, 1.00], $z = -1.15$, $p = .050$) were not. However, only the comparison between divorce and verbal abuse persisted after adjusting for education (Table 6). In contrast, all the three most common ACE pairs were exchangeable as indicated by a lack of statistical significance for the heterogeneity tests, both with and without

adjustment for education (Table 6). Thus, smoking prevalence was similar across the top three pairwise clusters (Table 6).

Discussion

Summary Findings

Using a nationally representative dataset that encompassed 21 states, this study described the form and prevalence of individual and co-occurring ACEs across different cumulative ACE exposures (one, two, three, and four). In addition, we tested the validity of the exchangeability assumption among the three most prevalent ACE elements within the single and double cumulative ACE exposure categories.

Our findings support previous literature regarding ACE prevalence and co-occurrence. For instance, we found 64.6% of surveyed adults reported at least one ACE, slightly above the prevalence range found in other literature, 52%-62.1% (Felitti et al., 1998; Slack et al., 2017). In addition, our ACE frequencies parallel the findings from another large U.S. study (Giano et al., 2020). Their ACE prevalence findings aligned with ours: 42% adults with 0 ACEs versus our 35.4%, 22.9% one ACE versus our 22.7%, 12.8% two ACEs versus our 13.0%, 8.2% three ACEs versus our 8.7% three ACEs, and 13.3% for four or more ACEs to our 20.2%. Thus, ACE exposures in these data are consistent with other U.S. population estimates.

This study further partitioned ACE exposures by examining the most common ACE components reported within each cumulative ACE exposure up to a score of four. Although a number of studies have reported overall exposure to individual ACEs, this is the first study to partition the exposure components. The most common individual ACEs, divorce, verbal abuse, and physical abuse, also co-occurred throughout increasing ACE combinations. For instance, we

found verbal abuse to be reported across all observed ACE counts and combinations up to four ACEs, which supports its high co-occurrence with other ACEs observed in previous literature (Downey et al., 2017; Giano et al., 2020). Verbal abuse also co-occurred with physical abuse at the two and three ACE counts. Verbal abuse and physical abuse co-occurred with intimate partner violence throughout all observed ACE combinations at the four ACE count. While the co-occurrence of ACEs is well documented, our study advances prior attempts to characterize clustering as they were limited to describing the percent of time a specific ACE co-occurred with another single ACE (Ramiro et al., 2010). Given that verbal abuse is a highly prevalent ACE it calls for more research exploring how and why verbal abuse co-occurs and the long-term consequences of exposure to this adversity (i.e., its association with lifetime depression; Gibb et al., 2007).

Adverse Childhood Experiences and Smoking

Consistent with the general cumulative model of adversity, where greater ACE exposure is associated with more health risks (Felitti et al., 1998), we found a dose-response association where higher ACEs were associated with higher smoking. However, our results showed that there is substantial variability in smoking prevalence when examining individual ACEs that comprise a specific ACE count. Therefore, our study addressed the previously untested assumption that individual ACEs (and ACE exposure categories) are equally prognostic for a given health outcome (Evans et al., 2013; Lacey & Minnis, 2020). Taken together, we found heterogeneity among the associations of the top three most prevalent single ACEs with current smoking status, but this was not observed for the top three ACE pairs. For instance, all the top three single ACEs were associated with different smoking prevalence, but only the difference

between persons experiencing divorce and those experiencing verbal abuse persisted after adjusting for education.

To consider the confounding influence of education level, we included it as a covariate in our regression models. Adjusting for education trivially altered smoking prevalence estimates for the overall one and two counts (< 0.2%). Further, education did not seem to influence the heterogeneity tests for ACE pairs, likely because there was no heterogeneity in the unadjusted model. Given that the heterogeneity between divorce and physical abuse was robust to education adjustment, this provides additional evidence (cf. Campbell et al., 2016) that all ACEs are not equally related to smoking.

Our study addressed Lacey and Minnis' (2020) call to a) understand which ACEs co-occur and b) whether ACE exposures are exchangeable. We present the first description of the prevalence and composition of ACE exposures within cumulative risk categories, and the first formal comparison of the exchangeability of these exposures in relation to current smoking. As noted in the introduction, heterogeneity among individual ACE exposures and smoking has been observed, although not formally evaluated, in previous literature (Campbell et al., 2016). Our study indicates that the type of adversity, as well as the number of adversities, is important. For instance, when we distinguished among singleton ACEs, we found different associations with smoking outcomes dependent on the specific ACE exposure. Specifically, people who only experienced divorce had a 4.3% higher smoking prevalence than those who experienced verbal abuse, adjusted for education. Those who only experienced verbal abuse smoked less than participants with any single ACE, indicating a possible a buffer for smoking and providing further evidence against the exchangeability of singleton ACEs. Additionally, the present study suggests that experiencing divorce is a more toxic exposure for smoking risk compared to verbal

abuse. Altogether, this evidence suggests that the common practice of classifying persons based upon their overall ACE exposure (i.e., the cumulative categorical risk model) masks important variation in smoking (cf. LaNoue et al., 2020). More broadly, this approach confirms the utility of considering the type of adversity, not just the quantity of adversities experienced. This distinction, in combination with the unique approach to identifying ACE clustering, may help clarify potential pathways for the association of ACEs with a variety of health outcomes.

In this regard, the potential pathways for the association of ACEs with smoking are complex. For instance, divorce pertains to different dimensions of social and psychological development (i.e., family structure) that may underlie the negative influence on smoking (Elliott et al., 2005; Topitzes, et al., 2010). Another perspective explains poor adult health via the impact of poverty and economics on the parents, which in turn increases the risk of ACEs in the household as adult family members cope with limited resources (Braveman et al., 2018). Therefore, families who experience divorce in the household may be vulnerable to financial limitations given the increased economic responsibility on a single parent, and this in turn may result in higher smoking prevalence. Additionally, the underlying driver of ACEs themselves may derive from parent's negative early childhood experiences that indirectly impact their parenting styles and philosophies such as sensitivity and responsiveness to their children (Steele et al., 2016). Thus, a parent's own upbringing may impact their adult relationships, which could manifest as divorce, and therefore also extend to their relationships with their own children. However, to the extent that parental upbringing is a general determinant of ACEs in the household, and not of divorce specifically, it would fail to capture the unique association observed between higher smoking among adults whose parents divorced.

This study also provided a technique to partition ACEs co-occurrence, providing a foundation to evaluate heterogeneity for other clusters and other health outcomes. This technique can lead to an improvement in understanding health inequalities through public health efforts. For instance, a nuanced understanding of the scope of adversities can allow medical providers and public health professionals to identify the most prevalent ACE combination for specific populations. This understanding can then be applied for specific target interventions through upstream public health approaches (Kinner & Borschmann, 2017). For instance, based on our results, medical providers could screen for specific ACEs (i.e., divorce) that suggest people would be more vulnerable for smoking risk but also free medical providers' focus if the type of adversity experienced is less associated with smoking risk (i.e., verbal abuse). This can lead to a compounding benefit called a triple dividend, which through effective responses to ACES, the health of adults now can lead to better health in the adults' future and health outcomes for their children. This is crucial because current predictors of smoking, such as the role of families and divorced families with a smoking background, could alert us to screen for potential smokers.

Limitations

This study is subject to several limitations. Although the ACE module captures experiences of child maltreatment and household dysfunction, it does not include adversities outside the home, i.e., community dysfunction, experienced discrimination, and living in foster care (Karatekin & Hill, 2019; Wade Jr. et al., 2016). These adverse experiences may be particularly important for children who live in poverty or who are ethnic/racial minorities. Like other ACE literature (Crouch et al., 2020; Lee & Chen, 2017) the design is cross-sectional, which can only demonstrate associations between ACEs and observed health outcomes and

cannot reveal causality. ACE exposure was measured in a binary manner (whether they were exposed to it or not) which does not account for the impact of the severity, frequency, and duration of the exposure (Lacey & Minnis, 2020). The heterogeneity evaluation was limited to single and double ACE exposures, and to a single health outcome. Given the complexity of higher order ACE clusters and the complexity of different ACE pathways to smoking (Topitzes et al., 2010), the underlying factors linking ACEs and current smoking remain to be determined. Thus, different heterogeneity patterns may be observed for different health outcomes, for other ACE combinations beyond the top three examined here, and for combinations within higher cumulative ACE exposures (i.e., 3 or 4).

Strengths

This study has several strengths. The sample size is large and representative of a substantial portion of the US population. Further, because our results are population-based, our results should be generalizable to the 21 states included in the study. Previous ACE literature has established the validity of retrospective recall of ACEs in adult populations (Hardt & Rutter, 2004) but agreement between concurrent and retrospective reports is moderate (Baldwin et al., 2021). We also used an optimal analytic strategy that compared groups using prevalence ratios which are more interpretable and less biased than odds ratios (Zou, 2004). Other models, such as the log-binomial, are appropriate for binary outcomes, although with large samples the estimates are essentially the same as with the present approach (Petersen & Deddens, 2008). We used a stable indicator of SES, education level, to examine the robustness of the heterogeneity tests. There are other SES indicators (i.e., income) but these usually contain higher nonresponse rates. Therefore, education was a defensible choice as an SES indicator in this study.

Outlook

In conclusion, this is the first study that described the composition and frequencies of ACE relationships beyond the single ACE count (Dube et al., 2003; Edwards et al., 2003). We built from previous literature that looked at conditional ACE combinations beyond the single ACE count based on specific ACE observations (ACE one *plus* ACE two *or* ACE three). We added to this conceptual framework by looking at the most naturally occurring ACE combinations at different ACE counts (Edwards et al., 2003). Our results demonstrate that singleton ACE exposures are not exchangeable, but that ACE pairs were exchangeable in terms of their association with smoking. Future research should explore these patterns with larger ACE compositions (i.e., ACE triplets) and other health outcomes.

References

- Almuneef, M., Qayad, M., Aleissa, M., & Albuhairan, F. (2014). Adverse childhood experiences, chronic diseases, and risky health behaviors in Saudi Arabian adults: A pilot study. *Child Abuse & Neglect*, 38(11), 1787–1793. <https://doi.org/10.1016/j.chiabu.2014.06.003>
- Anda, R. F., Croft, J. B., Felitti, V. J., Nordenberg, D., Giles, W. H., Williamson, D. F., & Giovino, G. A. (1999). Adverse childhood experiences and smoking during adolescence and adulthood. *Journal of the American Medical Association*, 282(17), 1652–1658. <https://doi.org/10.1001/jama.282.17.1652>
- Baldwin, J. R., Caspi, A., Meehan, A. J., Ambler, A., Arseneault, L., Fisher, H. L., ... & Danese, A. (2021). Population vs individual prediction of poor health from results of adverse childhood experiences screening. *Journal of the American Medical Association Pediatrics*, 175(4), 385–393. <https://doi.org/10.1001/jamapediatrics.2020.5602>
- Barile, J. P., Edwards, V. J., Dhingra, S. S., & Thompson, W. W. (2015). Associations among county-level social determinants of health, child maltreatment, and emotional support on health-related quality of life in adulthood. *Psychology of Violence*, 5(2), 183. <http://dx.doi.org/10.1037/a0038841>
- Bellis, M. A., Hughes, K., Leckenby, N., Jones, L., Baban, A., Kachaeva, M., Povilaitis, R., Pudule, I., Qirjako, G., Ulukol, B., Raleva, M., & Terzic, N. (2014a). Adverse childhood experiences and associations with health-harming behaviours in young adults: Surveys in eight Eastern European countries. *Bulletin of the World Health Organization*, 92, 641–655. <https://doi.org/10.2471/BLT.13.129247>
- Bellis, M. A., Lowey, H., Leckenby, N., Hughes, K., & Harrison, D. (2014b). Adverse childhood experiences: Retrospective study to determine their impact on adult health behaviours and health outcomes in a UK population. *Journal of Public Health*, 36(1), 81–91. <https://doi.org/10.1093/pubmed/fdt038>
- Braveman, P., Heck, K., Egerter, S., Rinki, C., Marchi, K., & Curtis, M. (2018). Economic hardship in childhood: a neglected issue in ACE studies?. *Maternal and Child Health Journal*, 22(3), 308–317. <https://doi.org/10.1007/s10995-017-2368-y>
- Campbell, J. A., Walker, R. J., & Egede, L. E. (2016). Associations between adverse childhood experiences, high-risk behaviors, and morbidity in adulthood. *American Journal of Preventive Medicine*, 50(3), 344–352. <https://doi.org/10.1016/j.amepre.2015.07.022>
- Centers for Disease Control and Prevention. (2021). *Preventing adverse childhood experiences*. https://www.cdc.gov/violenceprevention/aces/fastfact.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fviolenceprevention%2Facestudy%2Ffastfact.html
- Centers for Disease Control and Prevention. (2020a). *CDC - 2019 BRFSS survey data and documentation*. https://www.cdc.gov/brfss/annual_data/annual_2019.html

Centers for Disease Control and Prevention. (2020b). Tobacco-related mortality. https://www.cdc.gov/tobacco/data_statistics/fact_sheets/health_effects/tobacco_related_mortality/index.htm

Centers for Disease Control and Prevention. (2020c). Fact sheets on smoking and tobacco use. Centers for Disease Control and Prevention. https://www.cdc.gov/tobacco/data_statistics/fact_sheets/index.htm

Centers for Disease Control and Prevention (1994). Cigarette smoking among adults--United States, 1992, and changes in the definition of current cigarette smoking. *MMWR. Morbidity and Mortality Weekly Report*, 43(19), 342-346.

Centers for Disease Control and Prevention (2010). National Center for Chronic Disease Prevention and Health Promotion (US), & Office on Smoking and Health (US). *How tobacco smoke causes disease: The biology and behavioral basis for smoking-attributable disease: A report of the surgeon general*. Centers for Disease Control and Prevention (US). <http://www.ncbi.nlm.nih.gov/books/NBK53017/>

Chang, X., Jiang, X., Mkandarwire, T., & Shen, M. (2019). Associations between adverse childhood experiences and health outcomes in adults aged 18–59 years. *PLoS One*, 14(2), e0211850. <https://doi.org/10.1371/journal.pone.0211850>

Chapman, D. P., Whitfield, C. L., Felitti, V. J., Dube, S. R., Edwards, V. J., & Anda, R. F. (2004). Adverse childhood experiences and the risk of depressive disorders in adulthood. *Journal of Affective Disorders*, 82(2), 217–225. <https://doi.org/10.1016/j.jad.2003.12.013>

Cornelius, M. E., Wang, T. W., Jamal, A., Loretan, C. G., & Neff, L. J. (2020). Tobacco product use among adults—United States, 2019. *Morbidity and Mortality Weekly Report*, 69(46), 1736. <https://doi.org/10.15585/mmwr.mm6946a4>

Crouch, E., Jones, J., Stropolis, M., & Merrick, M. (2020). Examining the association between ACEs, childhood poverty and neglect, and physical and mental health: Data from two state samples. *Children and Youth Services Review*, 116, 105155. <https://doi.org/10.1016/j.chilyouth.2020.105155>

Danese, A., Moffitt, T., Harrington, H., Milne, B., Polanczyk, G., Pariante, C., Poulton, R., & Caspi, A. (2009). Adverse childhood experiences and adult risk factors for age-related disease: Depression, inflammation, and clustering of metabolic risk markers. *Archives of Pediatrics & Adolescent Medicine*, 163, 1135–1143. <https://doi.org/10.1001/archpediatrics.2009.214>

Dong, M., Anda, R. F., Felitti, V. J., Dube, S. R., Williamson, D. F., Thompson, T. J., Loo, C. M., & Giles, W. H. (2004). The interrelatedness of multiple forms of childhood abuse, neglect, and household dysfunction. *Child Abuse & Neglect*, 28(7), 771–784. <https://doi.org/10.1016/j.chiabu.2004.01.008>

Downey, J. C., Gudmunson, C. G., Pang, Y. C., & Lee, K. (2017). Adverse childhood experiences affect health risk behaviors and chronic health of Iowans. *Journal of Family Violence*, 32(6), 557–564. <https://doi.org/10.1007/s10896-017-9909-4>

- Dube, S. R., Felitti, V. J., Dong, M., Chapman, D. P., Giles, W. H., & Anda, R. F. (2003). Childhood abuse, neglect, and household dysfunction and the risk of illicit drug use: The adverse childhood experiences study. *Pediatrics*, *111*(3), 564–572. <https://doi.org/10.1542/peds.111.3.564>
- Edwards, V. J., Holden, G. W., Felitti, V. J., & Anda, R. F. (2003). Relationship between multiple forms of childhood maltreatment and adult mental health in community respondents: Results from the adverse childhood experiences study. *American Journal of Psychiatry*, *160*(8), 1453–1460. <https://doi.org/10.1176/appi.ajp.160.8.1453>
- Elliott, G. C., Cunningham, S. M., Linder, M., Colangelo, M., & Gross, M. (2005). Child physical abuse and self-perceived social isolation among adolescents. *Journal of Interpersonal Violence*, *20*(12), 1663–1684.
- Evans, G. W., Li, D., & Whipple, S. S. (2013). Cumulative risk and child development. *Psychological Bulletin*, *139*(6), 1342–1396. <https://doi.org/10.1037/a0031808>
- Felitti, V. J., Anda, R. F., Nordenberg, D., Williamson, D. F., Spitz, A. M., Edwards, V., Koss, M. P., & Marks, J. S. (1998). Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults. *American Journal of Preventive Medicine*, *14*(4), 245–258. [https://doi.org/10.1016/S0749-3797\(98\)00017-8](https://doi.org/10.1016/S0749-3797(98)00017-8)
- Ford, E. S., Anda, R. F., Edwards, V. J., Perry, G. S., Zhao, G., Li, C., & Croft, J. B. (2011). Adverse childhood experiences and smoking status in five states. *Preventive Medicine*, *53*(3), 188–193. <https://doi.org/10.1016/j.ypmed.2011.06.015>
- Ford, K., Butler, N., Hughes, K., Quigg, Z., Bellis, M. A., & Barker, P. (2016). Adverse childhood experiences (ACEs) in Hertfordshire, Luton and Northamptonshire. *Liverpool: Liverpool John Moores University*.
- Font, S. A., & Maguire-Jack, K. (2016). Pathways from childhood abuse and other adversities to adult health risks: The role of adult socioeconomic conditions. *Child Abuse & Neglect*, *51*, 390–399. <https://doi.org/10.1016/j.chiabu.2015.05.013>
- Gelman, A., & Stern, H. (2006). The difference between “significant” and “not significant” is not itself statistically significant. *The American Statistician*, *60*(4), 328–331.
- Giano, Z., Wheeler, D. L., & Hubach, R. D. (2020). The frequencies and disparities of adverse childhood experiences in the US. *BMC Public Health*, *20*(1), 1–12. <https://doi.org/10.1186/s12889-020-09411-z>
- Gibb, B. E., Benas, J. S., Crossett, S. E., & Uhrlass, D. J. (2007). Emotional maltreatment and verbal victimization in childhood. *Journal of Emotional Abuse*, *7*(2), 59–73. doi:10.1300/j135v07n02_04.
- Gilbert, L. K., Breiding, M. J., Merrick, M. T., Thompson, W. W., Ford, D. C., Dhingra, S. S., & Parks, S. E. (2015). Childhood adversity and adult chronic disease. *American Journal of Preventive Medicine*, *48*(3), 345–349. <https://doi.org/10.1016/j.amepre.2014.09.006>

Hardt, J., & Rutter, M. (2004). Validity of adult retrospective reports of adverse childhood experiences: review of the evidence. *Journal of Child Psychology and Psychiatry*, 45(2), 260-273. <https://doi.org/10.1111/j.1469-7610.2004.00218.x>

Karatekin, C., & Hill, M. (2019). Expanding the original definition of adverse childhood experiences (ACEs). *Journal of Child & Adolescent Trauma*, 12(3), 289-306. <https://doi.org/10.1007/s40653-018-0237-5>

Kaufman, J. S., & MacLehose, R. F. (2013). Which of these things is not like the others?. *Cancer*, 119(24), 4216-4222. <https://doi.org/10.1002/cncr.28359>

Kim, Y., Lee, H., & Park, A. (2020). Adverse childhood experiences, economic hardship, and obesity: Differences by gender. *Children and Youth Services Review*, 116, 105214. <https://doi.org/10.1016/j.chilyouth.2020.105214>

Lacey, R. E., Pinto Pereira, S. M., Li, L., & Danese, A. (2020). Adverse childhood experiences and adult inflammation: Single adversity, cumulative risk and latent class approaches. *Brain, Behavior, and Immunity*, 87, 820–830. <https://doi.org/10.1016/j.bbi.2020.03.017>

Lacey, R. E., & Minnis, H. (2020). Practitioner review: Twenty years of research with adverse childhood experience scores – advantages, disadvantages and applications to practice. *Journal of Child Psychology and Psychiatry*, 61(2), 116–130. <https://doi.org/10.1111/jcpp.13135>

LaNoue, M. D., George, B. J., Helitzer, D. L., & Keith, S. W. (2020). Contrasting cumulative risk and multiple individual risk models of the relationship between adverse childhood experiences (ACEs) and adult health outcomes. *BMC Medical Research Methodology*, 20(1), 239. <https://doi.org/10.1186/s12874-020-01120-w>

Lee, R. D., & Chen, J. (2017). Adverse childhood experiences, mental health, and excessive alcohol use: Examination of race/ethnicity and sex differences. *Child Abuse & Neglect*, 69, 40-48. <https://doi.org/10.1016/j.chiabu.2017.04.004>

Long, J. S. (2009). *The workflow of data analysis using Stata*. Stata Press.

Loudermilk, E., Loudermilk, K., Obenauer, J., & Quinn, M. A. (2018). Impact of adverse childhood experiences (ACEs) on adult alcohol consumption behaviors. *Child Abuse & Neglect*, 86, 368–374. <https://doi.org/10.1016/j.chiabu.2018.08.006>

Merrick, M. T., Ford, D. C., Ports, K. A., & Guinn, A. S. (2018). Prevalence of adverse childhood experiences from the 2011-2014 behavioral risk factor surveillance system in 23 states. *Journal of the American Medical Association Pediatrics*, 172(11), 1038–1044. <https://doi.org/10.1001/jamapediatrics.2018.2537>

Nelson, D. E., Powell-Griner, E., Town, M., & Kovar, M. G. (2003). A comparison of national estimates from the national health interview survey and the behavioral risk factor surveillance system. *American Journal of Public Health*, 93(8), 1335-1341.

- Olofson, M. W. (2018). A new measurement of adverse childhood experiences drawn from the panel study of income dynamics child development supplement. *Child Indicators Research*, 11(2), 629–647. <https://doi.org/10.1007/s12187-017-9455-x>
- Petersen, M. R., & Deddens, J. A. (2008). A comparison of two methods for estimating prevalence ratios. *BMC Medical Research Methodology*, 8(1), 1-9. <https://doi.org/10.1186/1471-2288-8-9>
- Ramiro, L. S., Madrid, B. J., & Brown, D. W. (2010). Adverse childhood experiences (ACE) and health-risk behaviors among adults in a developing country setting. *Child Abuse & Neglect*, 34(11), 842–855. <https://doi.org/10.1016/j.chiabu.2010.02.012>
- Slack, K. S., Font, S. A., & Jones, J. (2017). The complex interplay of adverse childhood experiences, race, and income. *Health & Social Work*, 42(1), e24–e31. <https://doi.org/10.1093/hsw/hlw059>
- Steele, H., Bate, J., Steele, M., Dube, S. R., Danskin, K., Knafo, H., ... & Murphy, A. (2016). Adverse childhood experiences, poverty, and parenting stress. *Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement*, 48(1), 32. <https://doi.org/10.1037/cbs0000034>
- Tsehay, M., Necho, M., & Mekonnen, W. (2020). The role of adverse childhood experience on depression symptom, prevalence, and severity among school going adolescents. *Depression Research and Treatment*, 2020, e5951792. <https://doi.org/10.1155/2020/5951792>
- Topitzes, J., Mersky, J. P., & Reynolds, A. J. (2010). Child maltreatment and adult cigarette smoking: A long-term developmental model. *Journal of Pediatric Psychology*, 35(5), 484-498. <https://doi.org/10.1093/jpepsy/jsp119>
- Wade Jr, R., Cronholm, P. F., Fein, J. A., Forke, C. M., Davis, M. B., Harkins-Schwarz, M., ... & Bair-Merritt, M. H. (2016). Household and community-level adverse childhood experiences and adult health outcomes in a diverse urban population. *Child Abuse & Neglect*, 52, 135-145. <https://doi.org/10.1016/j.chiabu.2015.11.021>
- Ye, D., & Reyes-Salvail, F. (2014). Adverse childhood experiences among Hawai'i adults: Findings from the 2010 behavioral risk factor survey. *Hawai'i Journal of Medicine & Public Health*, 73(6), 181–190.
- Zou, G. (2004). A modified poisson regression approach to prospective studies with binary data. *American Journal of Epidemiology*, 159(7), 702-706.

Table 1.												
<i>Participant Demographics and Cumulative Exposure to Adverse Childhood Experiences</i>												
	Total Sample		Number of Adverse Childhood Experiences									
			0		1		2		3		4 or more	
Participants, <i>N</i>	115,230		45,824		25,982		14,523		9,212		19,689	
Age years, mean, <i>SD</i>	49.0	18.9	53.2	20.3	49.7	18.9	48.6	18.2	46.8	17.1	44.3	16.6
Female sex, % <i>N</i>	51.9	64,319	51.8	25,492	48.5	13,774	49.1	7,761	50.9	5,094	58.2	12,198
Male sex, % <i>N</i>	48.1	50,911	48.2	20,332	51.5	12,208	50.9	6,762	49.1	4,118	41.8	7,491
Race/ethnicity, % <i>N</i>												
Non-Hispanic White	72.4	93,305	74.9	38,487	71.3	20,905	72.7	11,612	70.6	7,279	69.7	15,022
Non-Hispanic Black	12.2	10,528	9.9	3,593	13.1	2,670	13.2	1,473	13.9	903	13.7	1,889
Non-Hispanic Asian	2.6	1,029	4.0	536	2.4	226	1.9	105	2.3	78	1.1	84
Native American	1.2	1,511	0.9	426	1.0	268	0.9	176	1.5	144	2.1	497
Hispanic	9.8	6,095	8.9	2,012	10.7	1,351	9.2	796	9.7	548	10.8	1,388
Other	1.8	2,762	1.3	770	1.60	562	2.1	361	2.1	260	2.6	809
Education level, % <i>N</i>												
Less than high school	11.2	8,042	10.3	2,880	10.8	1,725	10.1	977	10.2	637	14.1	1,823
High school	30.0	32,822	29.8	13,062	30.0	7,449	29.0	3,956	29.0	2,563	31.4	5,792

graduate												
Some college	30.8	32,405	27.6	11,736	30.3	7,101	31.6	4,231	34.3	2,840	34.8	6,497
College education or higher	28.1	41,961	32.2	18,146	28.8	9,707	29.3	5,359	26.4	3,172	19.7	5,577
Marital status, % <i>N</i>												
Married	51.1	58,850	58.2	25,513	51.1	13,385	49.3	7,322	47.8	4,374	40.9	8,256
Divorced	10.9	16,107	8.8	5,137	11.0	3,550	11.5	2,229	12.5	1,508	13.5	3,683
Widowed	7.4	15,906	10.2	8,104	7.5	3,639	6.1	1,615	5.5	975	4.3	1,573
Separated	2.3	2,313	1.5	625	2.3	472	2.5	292	2.2	224	3.5	700
Never married	23.4	18,175	18.0	5,464	23.4	4,122	26.1	2,565	25.1	1,721	30.2	4,303
Smoking status, % <i>N</i>												
Never/former smoker	83.2	97,599	89.9	41,350	85.3	22,501	82.5	12,182	80.1	7,451	70.9	14,115
Current smoker	16.8	17,631	10.1	4,474	14.7	3,481	17.5	2,341	19.9	1,761	29.1	5,574

Note. Percents are weighted to reflect the adult civilian noninstitutionalized population of 21 participating US states.

Table 2.*Weighted Percentages of Individual Adverse Childhood Experiences in the 2019 BRFSS*

ACE	Percent	95% CI
Mental illness in household		
Never experienced	81.6	(81.2, 82.0)
Experienced once or > 1 times	18.4	(18.0, 18.8)
Problem drinker in household		
Never experienced	77.1	(76.7, 77.6)
Experienced once or > 1 times	22.9	(22.5, 23.4)
Drug use in household		
Never experienced	88.7	(88.4, 89.0)
Experienced once or > 1 times	11.3	(11.0, 11.7)
Incarcerated family member in household		
Never experienced	91.3	(90.9, 91.6)
Experienced once or > 1 times	8.8	(8.4, 9.1)
Divorce in household		
Never experienced	70.7	(70.2, 71.3)
Experienced once or > 1 times	29.3	(28.7, 29.8)
IPV in household*		
Never experienced	83.2	(82.8, 83.6)
Experienced once or > 1 times	16.8	(16.4, 17.2)
Physical abuse in household		
Never experienced	75.8	(75.3, 76.3)
Experienced once or > 1 times	24.2	(23.7, 24.7)
Verbal abuse in household		
Never experienced	65.9	(65.3, 66.4)
Experienced once or > 1 times	34.1	(33.6, 34.7)
Sex abuse-touched in household**		
Never experienced	88.9	(88.5, 89.2)
Experienced once or > 1 times	11.1	(10.8, 11.5)
Sex abuse-touch other in household***		
Never experienced	91.6	(91.3, 91.9)
Experienced once or > 1 times	8.4	(8.1, 8.8)
Sex abuse-forced in household****		
Never experienced	94.9	(94.7, 95.2)
Experienced once or > 1 times	5.1	(4.8, 5.3)

Note. *IPV was intimate partner violence. Percents are weighted to reflect the adult civilian noninstitutionalized population of 21 participating US states.

**Sex abuse-touched was if the participant was touched sexually by an adult or anyone 5 years older than them.

***Sex abuse-touch other was if the participant was forced to sexually touch an adult or anyone 5 years older than them.

***** Sex abuse-forced was if the participant was forced to have sex with an adult or anyone 5 years older than them.

Table 3.

Percentages of Adverse Childhood Experience (ACE) Count-based Exposures and the Top Five Most Commonly Occurring ACEs Within Counts

Number of ACEs	Percent	95% CI	N
0	35.4	(34.9, 35.9)	45,824
1	22.7	(22.3, 23.2)	25,982
Divorce	7.3	(7.0, 7.6)	6,811
Verbal abuse	5.6	(5.3, 5.9)	6,392
Physical abuse	3.2	(3.0, 3.4)	3,931
Problem drinker	2.4	(2.3, 2.5)	3,661
Mental illness	1.7	(1.6, 1.9)	2,087
All other single ACEs	2.5	(2.3, 2.7)	3,100
2	13.0	(12.6, 13.4)	14,523
Physical abuse/verbal abuse	1.9	(1.8, 2.1)	2,205
Divorce/verbal abuse	1.5	(1.3, 1.6)	1,396
Problem drinker/verbal abuse	0.9	(0.8, 1.0)	1,248
Divorce/problem drinker	1.0	(0.9, 1.0)	1,093
Verbal abuse/mental illness	1.0	(0.9, 1.1)	1,030
All other double ACEs	6.7	(6.4, 7.0)	7,551
3	8.7	(8.4, 9.0)	9,212
Physical abuse/verbal abuse/IPV	0.6	(0.5, 0.7)	77
Divorce/physical abuse/verbal abuse	0.7	(0.6, 0.9)	631
Problem drinker/physical abuse/verbal abuse	0.5	(0.4, 0.5)	548
Mental illness/ physical abuse/verbal abuse	0.5	(0.4, 0.6)	526
Divorce/ problem drinker /verbal abuse	0.5	(0.4, 0.6)	464
All other triple ACEs	5.9	(5.6, 6.2)	6,336
4	6.5	(6.2, 6.8)	6,660
IPV/ problem drinker /physical abuse/verbal abuse	0.5	(0.5, 0.6)	675
IPV/ problem drinker /verbal abuse/divorce	0.5	(0.4, 0.5)	444
IPV/ problem drinker /physical abuse/verbal abuse	0.2	(0.2, 0.3)	295
IPV/mental illness/physical abuse/verbal abuse	0.3	(0.2, 0.3)	285
IPV/problem drinker/verbal abuse/divorce	0.2	(0.2, 0.2)	266

All other quadruple ACEs	4.8	(4.6, 5.0)	4,695
5 or more	13.7	(13.3, 14.1)	13,029

Note. Percents are weighted to reflect the adult civilian noninstitutionalized population of 21 participating US states. Frequency of clusters are reported in descending order based upon unweighted 2019 data.

Divorce was if the participants' parents were divorced or separated. Verbal abuse was if the participant was ever sworn/insulted/put down. Physical abuse was if the participant was hit, kicked, beaten or physically hurt in any way. Mental illness represents whether the respondent reported mental illness/depression in the household. Problem drinkers were problem drinkers or alcoholism in the household. IPV was intimate partner violence in the household.

Table 4.*Incidence Rate Ratios for the Regression of Current Smoking on Adverse Childhood Experiences (ACEs)*

Adverse Childhood Experiences	Unadjusted		Adjusted	
	IRR	95% CI	IRR	95% CI
0 ACE	1.0	-	1.0	-
1 ACE	1.46	(1.35, 1.57)	1.42	(1.31, 1.53)
Divorce	1.85	(1.66, 2.06)	1.64	(1.47, 1.83)
Verbal abuse	1.13	(0.99, 1.30)	1.25	(1.09, 1.43)
Physical abuse	1.40	(1.19, 1.64)	1.36	(1.16, 1.59)
2 ACE	1.73	(1.59, 1.88)	1.70	(1.57, 1.85)
Physical abuse/verbal abuse	1.56	(1.28, 1.91)	1.63	(1.35, 1.98)
Verbal abuse/divorce	1.97	(1.67, 2.33)	1.92	(1.63, 2.27)
Problem drinker/verbal abuse	1.58	(1.22, 2.04)	1.67	(1.29, 2.16)

Note. Only the most common three singleton and double ACEs are displayed.

Adjusted models were adjusted for an indicator education variable coded as less than high school; high school graduate; some college; college graduate or higher.

Divorce was if the participants' parents were divorced or separated. Verbal abuse was if the participant was ever sworn, insulted, or put down. Physical abuse was if the participant was hit, kicked, beaten or physically hurt in any way. Problem drinker was if the participant was exposed to a problem drinker or alcoholism in the household.

Table 5.*Smoking Percentages by Adverse Childhood Experiences (ACEs) at Different ACE Exposures*

Adverse Childhood Experience	Unadjusted		Adjusted	
	%	95% CI	%	95% CI
0 ACE	10.1	(9.6, 10.6)	10.2	(9.7, 10.7)
1 ACE	14.7	(13.9, 15.6)	14.5	(13.7, 15.3)
Divorce	18.7	(16.9, 20.5)	16.9	(15.3, 18.6)
Verbal abuse	11.5	(10.0, 12.9)	12.5	(10.9, 14.1)
Physical abuse	14.2	(12.0, 16.3)	13.7	(11.7, 15.8)
2 ACE	17.5	(16.3, 18.6)	17.3	(16.2, 18.4)
Physical abuse/verbal abuse	15.8	(12.8, 18.9)	16.5	(13.4, 19.6)
Verbal abuse/divorce	19.9	(16.8, 23.1)	19.5	(16.4, 22.5)
Problem drinker/Verbal abuse	16.0	(12.0, 20.0)	16.9	(12.6, 21.1)

Note. Smoking proportions for the most common three singleton and double ACE exposures.

Adjusted models were adjusted for an indicator education variable coded as less than high school; high school graduate; some college; college graduate or higher.

Divorce was if the participants' parents were divorced or separated. Verbal abuse was if the participant was ever sworn, insulted, or put down. Physical abuse was if the participant was hit, kicked, beaten or physically hurt in any way. Problem drinker was if the participant was exposed to a problem drinker or alcoholism in the household.

Table 6.*Heterogeneity Tests for Single and Double Adverse Childhood Experiences Regression Coefficients (ACEs) on Current Smoking*

Single ACEs				
	Unadjusted		Adjusted	
	Verbal abuse	Physical abuse	Verbal abuse	Physical abuse
Divorce				
Ratio [95% CI]	1.63 (1.37, 1.94)	1.32 (1.09, 1.60)	1.36 (1.14, 1.63)	1.17 (0.96, 1.41)
<i>z</i> statistic	5.43	2.81	3.46	1.59
<i>p</i> -value	<i>p</i> < .001	<i>p</i> = .004	<i>p</i> = .001	<i>p</i> = .113
Verbal abuse				
Ratio [95% CI]		0.81 (0.66, 1.00)		0.85 (0.69, 1.06)
<i>z</i> statistic		-1.95		-1.45
<i>p</i> -value		<i>p</i> = .050*		<i>p</i> = .148
Double ACEs				
	Unadjusted		Adjusted	
	Verbal abuse divorce	Verbal abuse problem drinker	Verbal abuse divorce	Verbal abuse problem drinker
Physical abuse				
Verbal abuse				
Ratio [95% CI]	0.79 (0.61, 1.02)	0.99 (0.72, 1.37)	0.87 (0.67, 1.12)	0.97 (0.70, 1.34)
<i>z</i> statistic	-1.74	-0.06	-1.06	-.20
<i>p</i> -value	<i>p</i> = .081	<i>p</i> = .952	<i>p</i> = .290	<i>p</i> = .844
Verbal abuse divorce				
Ratio [95% CI]		1.24 (0.92, 1.69)		1.11 (0.81, 1.52)
<i>z</i> statistic		1.41		.65
<i>p</i> -value		<i>p</i> = .157		<i>p</i> = .514

Note. Adjusted models were adjusted for an indicator education variable coded as less than high school; high school graduate; some college; college graduate or higher.

Divorce was if the participants' parents were divorced or separated. Verbal abuse was if the participant was ever sworn/insulted/put down. Physical abuse was if the participant was hit/kick/beat or physically hurt in any way. Problem drinkers were problem drinker/alcoholism in the household.

*The exact value was 0.0504