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Externalizing Problems in Children: Examining the Role of Caregiver and Child Adversities and Parental Involvement

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ABSTRACT

Previous research has shown that exposure to adverse childhood experiences (ACEs) is associated with increased behavior problems in children. Few studies, however, have taken a multi-informant approach to examine how different factors involving both the child and caregiver affect children's externalizing problems. Guided by Bowen's Family Systems Theory, the current study examined how child age and gender, caregiver age, household income, child and caregiver adversity, and child and caregiver report of caregiver involvement were associated with children's externalizing problems. The sample included 65 caregiver-child dyads recruited from community organizations in the Midsouth, United States. Youth were aged 6-12 years and primarily identified as Black or African American (95.45%) and as boys (54.55%). Two linear regression models were run with caregiver-report of child externalizing problems as the dependent variable in both models. One model focused on child variables, including child age, child gender, child adversity, and child-report of parental involvement, while the other centered caregiver variables, including caregiver age, income, caregiver ACEs, and caregiver report of their own parental involvement. Only the caregiver model was significant, with more caregiver ACEs related to higher child externalizing problems. None of the other independent variables were related to child externalizing problems. These results demonstrate the impact of caregiver's history of adversity on child functioning. Interventions that target children's externalizing problems may benefit from incorporating an assessment of parent adversity history. Future research should explore underlying mechanisms that may explain this association to identify modifiable factors that could be included in treatments for youth experiencing externalizing problems.

KEYWORDS

Intergenerational; Behavior Problems; Adverse Childhood Experiences; ACEs; Caregiver-child Dyads; Youth Functioning; Family Systems; Multi-informant

INTRODUCTION

Felitti and colleagues pioneered the study of adverse childhood experiences (ACEs), which include different types of abuse, neglect, and household dysfunction.¹ Over the past 25 years, ACEs have been widely researched across different populations and developmental epochs.^{2,3} ACEs have been linked to short- and long-term mental health difficulties, such as behavior problems, depression, and anxiety,⁴ as well as physical health problems in youth.⁵ It is rare that ACEs only affect the person who experienced the adversity as there is ample evidence of intergenerational transmission of risk, which involves the transmission of the impacts of traumatic events from caregiver to child.^{6,7} For example, caregiver ACEs have been associated with externalizing behaviors in their children.⁸ Although past research has shown the potential consequences of both direct and intergenerational adversity, less is known about other factors beyond caregiver and child ACEs that may be related to child externalizing behaviors, such as parenting practices. The current study examined how parenting practices (i.e., parental involvement), caregiver's exposure to adversity during their childhood, and children's own adversity exposure were related to children's externalizing problems.

Externalizing problems in children

Externalizing problems involve outward behaviors that cause conflict between the individual and their environment; they typically develop in childhood and adolescence.^{9,10} In school-aged children, externalizing problems may manifest as defiance, hyperactivity, lying, and aggression.¹¹ Common behaviors of youth with externalizing problems are physical aggression and rule breaking.¹⁰ Studies also suggest that relational and indirect aggression, such as hostility and social exclusion, should be included as part of the

spectrum of externalizing problems.¹² Youth who exhibit externalizing problems are at risk for developing oppositional defiant disorder (ODD) and increased involvement with the criminal legal system,¹³ as well as substance misuse in adulthood.¹⁴ Externalizing problems, particularly hyperactivity, in middle childhood have been associated with the development of attention-deficit/hyperactivity disorder (ADHD) in adolescence.¹⁵ According to the Centers for Disease Control and Prevention,¹⁶ approximately six million American children (9.8%) aged 3-17 have received an ADHD diagnosis. Additionally, approximately 5.8 million American children (8.9%) experience behavioral problems (*e.g.*, defiance, hyperactivity, impulsivity), demonstrating the need to further explore factors that may increase the expression of, as well as factors that may mitigate, externalizing problems.

Child adversity, caregiver adversity & externalizing problems

Past research has identified potential risk factors for the onset and maintenance of externalizing problems, such as child abuse and neglect.¹⁷ Research has also begun to uncover intergenerational impacts. For example, Yoon and colleagues found that when young mothers were exposed to adversity in their childhood, they were more likely to experience parenting stress and utilize physical discipline, which was then linked to aggression and rule-breaking behavior in their children.¹⁸

Research shows a link between experiencing abuse and neglect during childhood and the onset of externalizing problems, specifically higher aggression.¹⁹ For example, physical abuse has been associated with higher aggressive and disruptive behaviors in preschool children.¹⁹ Another factor related to higher externalizing problems in children is being exposed to a caregiver who misuses substances.²⁰ Manly and colleagues found that abuse, neglect, and being exposed to a family member with a substance use disorder were associated with a higher risk for developing externalizing problems.²⁰ Another adversity related to increased externalizing problems is experiencing community violence.²⁰ Further, stressors such as the death of a family member, family discord, and income loss were linked to an increased risk for externalizing problems.^{21, 22} Research shows that most children will experience at least one adverse event,²³ and a significant number will endure multiple adversities.²⁴ Polyvictimization, as defined by Finkelhor and colleagues,²⁵ is the occurrence of multiple types of adverse experiences. Studies have repeatedly found that polyvictimization is associated with behavior problems and aggression,²⁶ and externalizing problems more broadly in youth.^{27, 28}

Caregiver's own exposure to ACEs can also have a significant effect on youth's functioning.²⁹ This is known as intergenerational transmission of risk.⁷ For example, maternal ACEs have been associated with children's externalizing problems.³⁰ Kang and colleagues explored the intergenerational transmission of risk in Korean mother-child dyads, with children ranging in age from 6 to 18 years old, and their results indicated that the more ACEs experienced by the mother, the higher the risk of her offspring developing externalizing problems.³¹ Like Kang and colleagues, Stepleton and colleagues found that for each additional ACE experienced by the caregiver, there was a moderate increase in externalizing behaviors in children.^{29, 31} Although these studies provide valuable information regarding the association between types of adversity and externalizing problems in children, several gaps remain in the literature. First, most of these studies were conducted with primarily White samples, so they are limited in racial diversity. Loheide-Neismann and colleagues found in their meta-analysis that 35 out of 42 studies examining the impact of maternal ACEs on child externalizing behaviors were conducted with a majority White population.³² Besides the overabundance of studies with a majority White sample, it is also important to assess a sample that is majority Black/African American because of differences in frequency of ACEs; Black/African American youth have an increased risk for exposure to ACEs due to systemic inequality and oppression.³³ Because of this systemic disparity, it is valuable to further understand the relation between exposure to adversity and psychosocial outcomes in diverse samples.³³ Second, many study samples represented a vast age range spanning from infancy to older adolescence despite evidence that externalizing problems manifest differently and change in frequency as children age.³⁴ Specifically, previous research has shown that externalizing problems often begin and increase in early childhood and then start to decline around early adolescence;²² thus, it is beneficial to examine externalizing problems in specific developmental epochs that would take this trend into account.²² The current study aimed to address these research gaps by evaluating a predominantly Black/African American sample of youth in the middle childhood years (*i.e.*, 6-12 years old). This age range has previously been shown to contain major transition points in childhood, including in the parent-child relationship.³⁴ Another missing component from past research concerning adversity is examining both caregiver and child adversity in the same study. Previous research typically evaluates one form of adversity despite evidence that they are associated with each other.³⁵

Theoretical framework: Family Systems Theory

Bowen's Family Systems Theory provides a conceptual foundation to understand how caregivers' and children's exposure to adversity may influence children's functioning.³⁶ This theory posits that family members influence each other based on their interactions with one another.³⁷ For instance, a mother demonstrating aggressive tendencies towards her children influences her child to develop aggressive behaviors.³⁸ Additionally, one of the qualities of Family Systems Theory is that it is circular, meaning

that each member has an influence on one another; in other words, just as the caregiver influences the child, the child also influences the caregiver.³⁹ For example, a child who has experienced adversity may develop behavior problems (*e.g.*, misconduct, aggression) that can affect how their caregiver parents them; parenting challenges could then lead to further issues for the child.⁴⁰ Family functioning and parenting are key points of transmission for how caregivers affect their offspring's mental health. Johnson and colleagues found a relation between caregiver exposure to ACEs and poorer family functioning, and this poorer functioning was associated with increased risk for externalizing problems in children.⁴⁰ Given that effective family functioning is associated with fewer youth externalizing problems, it is critical to examine factors linked to effective family functioning, such as positive parenting.

Positive parenting practices

Knerr and colleagues found that parenting practices have a strong influence on children's mental health, including externalizing problems.⁴¹ Shelton and colleagues illustrated how parenting practices fall into different categories; one of which is positive parenting practices, which includes parental involvement.⁴² Parental involvement is defined as taking an active role in the child's life. This can be represented by attending the child's social activities (*e.g.*, clubs, sports), as well as supporting the child emotionally, for example, helping them process their feelings.⁴³ Anderson and colleagues found that among caregivers exposed to ACEs, those who exhibited more open and involved parenting had children with fewer externalizing problems.⁸ Meanwhile, caregivers who did not display positive parenting practices had children with more externalizing problems. Anderson and colleagues proposed that a lack of open communication and support serves as an obstacle to the development of self-regulation and emotion regulation skills in children.⁸ This link between higher levels of parental involvement and lower externalizing problems has been found in diverse samples of youth, including African American children.⁴⁴ Notably, there is inconsistency across studies, with some research not identifying a significant relation between involvement and externalizing problems.⁴⁵ Considering the variable findings in the literature, more work is needed to understand the relation between positive parenting practices and youth externalizing problems, especially among racially diverse samples. Previous research has explored how caregivers view the effects of their parental involvement, but much less work has been done on children's perceptions of parental involvement. Child-report of parenting practices is critically important because children provide a unique perspective that is generally lacking from past research.⁴⁶ Importantly, a small body of work has noted discrepancies in children's and caregiver's reports of parenting; typically, caregivers rate themselves higher on dimensions of parenting compared to children's ratings.⁴⁷ Such findings underscore the need to examine both child and parent reports of parenting practices.

Demographic factors

Previous research has identified demographic variables that may influence children's externalizing problems, such as gender, income, and age. Bem detailed how a child's sex-based preferences, skills, and behaviors are influenced by the gender roles placed on them by their guardians and authority figures.⁴⁸ In past work, there is a focus on boys' externalizing behaviors because of a perceived higher aggression rate among boys than girls.⁴⁹ Previous research has also shown that rule-breaking and aggressive behaviors are related to externalizing problems at a higher rate for boys than girls.⁵⁰ Notably, other studies are inconclusive about the role gender plays in child behavior. For instance, Flores and colleagues concluded that gender was not a significant factor in predicting externalizing problems in youth.⁵¹ Thus, the current study sought to clarify the relation between child gender and externalizing behaviors.

Other demographic factors have been consistently related to externalizing problems in youth. For example, previous research has shown that the lower the family income, the higher the risk for externalizing problems in youth⁵², and this has been evident in African American samples, as well.⁵³ Further, economic hardship can have a significant effect on the family system, parenting practices, and the effects of parenting on children's functioning.⁵⁴ Child age is another factor to account for when examining externalizing behaviors. Past research has found that as youth age, their externalizing problems lower.⁵⁶ Even within specific developmental epochs (*i.e.*, middle childhood), there is evidence of a relation between age and externalizing behaviors⁵⁷. Finally, there is also evidence that caregiver age can play a role in their report of youth's externalizing behaviors. Carneiro and colleagues conducted a review of the literature and found multiple studies in which maternal age was significantly associated with child behavioral problems in school.⁵⁸ More specifically, younger maternal age was linked to higher risk of behavioral problems in children.⁵⁸ Previous research seems to coalesce around the finding that family income, child age, and caregiver age can influence reports of youth externalizing behaviors; thus, the current study controlled for the effects of these variables when examining youth externalizing problems.

The current study

Previous research has shown a connection between children's direct and intergenerational exposure to adversity and their externalizing problems.^{20,31} Further, studies indicate that there is a significant inverse association between parental involvement and child externalizing problems.⁸ It is necessary to take a multi-informant approach to this work by examining both caregiver and child report of their own adversity, as well as caregiver and child report of parental involvement, to develop a comprehensive understanding of how these factors are related to children's externalizing problems. It is also important to consider the role of known influential demographic factors, such as age, gender, and income. Although previous literature has explored factors that increase the risk for externalizing problems in children,^{20,30} there is a need to expand this research to non-White majority samples and to focus on a specific developmental period. It was hypothesized that 1) more caregiver exposure to adverse childhood experiences would be associated with more child externalizing problems, 2) more child exposure to adversities would be associated with more child externalizing problems, 3) less caregiver involvement, per child and caregiver report, would be associated with more child externalizing problems, and 4) identifying as a boy would be associated with more externalizing problems. Analyses controlled for household income, caregiver age, and child age.

METHODS AND PROCEDURES*Participants*

Participants included 65 caregiver-youth dyads. Youth ranged in age from 6 to 12 years ($M = 9.11$, $SD = 2.25$) and caregivers ranged in age from 23 to 67 years ($M = 36.67$, $SD = 9.32$). Caregivers predominantly identified as Black or African American (93.93%), 3.03% identified as White or European American, 1.52% identified as biracial or multiracial, and 1.52% identified as another race. Among youth, 95.45% identified as African American or Black, 3.03% identified as White or European American, and 1.52% identified as American Indian or Alaskan Native. The relationship between caregivers and offspring was largely biological mother-child dyads (83.33%). Most of the youth identified as boys (54.55%) and the rest identified as girls (45.45%). The caregiver sample predominantly identified as female (98.48%). Caregiver's annual income ranged from less than \$5,000 to greater than \$50,001; 27.27% reported receiving less than \$5,000 a year, 24.24% made \$5,001 - \$10,000, 15.15% made \$10,001 - \$15,000, 6.06% made \$15,001 - \$20,000, 10.61% made \$20,001 - \$30,000, 6.06% made \$30,001 - \$40,000, 6.06% made \$40,001 - \$50,000, and 4.55% made above \$50,001.

Procedure

Following institutional review board approval, participants were recruited from community programs in a mid-sized city in the Midsouth, United States. Data for this study were drawn from a larger project. Inclusion criteria for the larger project were that families spoke English fluently and received services from local community organizations. Further, caregivers had to be at least 18 years old and the primary caregiver of a child three months to 17 years old. For the current study, children had to be between the ages of 6-12 years and not have cognitive or sensory impairments that would impede their ability to participate in an interview. This age range was selected to align with study measures that were validated for youth aged 6-12 years. Caregivers who were interested and eligible provided informed consent and permission for their child to participate; child participants provided assent. Caregivers and youth completed separate interviews with a trained study staff member. Specifically, study staff read each item aloud to the participant and recorded their responses on a paper copy or directly into a computer software program (i.e., Qualtrics). Reading each item aloud helped account for differences in literacy across participants, and provided an opportunity for the staff member to clarify items if a participant did not understand the prompt. Interviews lasted approximately 90 minutes. Caregivers and youth each received a \$30 gift card for their participation in the study. Caregivers also received a list of resources for local and national mental health services.

*Measures**Demographics*

A demographics questionnaire was completed by both child and caregiver participants. Both the caregiver and child were asked to report on the race and gender with which they identify, as well as their age. The options for both caregiver and child for gender included male, female, or other. Children also reported on their relationship to their caregivers (e.g., biological mother, biological father, stepmother, adoptive father). The caregiver was asked about the family's annual household income with the question phrased as, "What is your total household income per year from all sources (including child support)?"

Behavior Assessment System for Children- Third Edition (BASC-3 PRS)

The BASC-3 PRS measures caregiver's perspective on the behavior of their children ranging from 2 to 21 years old in the domains of externalizing, internalizing, and adaptive behaviors.⁵⁹ There are three versions of the measure based on child age; two

were used in this study: the Child form for ages 6-11 and the Adolescent form for ages 12-21. On the Child form, there are 175 items with four answer choices ranging from “Never” to “Always”. On the Adolescent form, there are 173 items with the same four response options of “Never” to “Always.” Q-global, an online scoring software program, was used to generate a norm-referenced t-score (mean of 50 and standard deviation of 10) for externalizing problems across all respondents, with higher scores reflecting greater symptomology. Scores from the BASC-3 PRS were aggregated using a composite scale. Previous examination of psychometric properties of the BASC-3 has shown that it has adequate internal consistency and test-retest reliability.⁵⁹ The BASC-3 has also shown adequate validity for African American/Black samples.⁶⁰ In the current study, Cronbach’s alpha was .96 for the caregiver-reported externalizing problems scale.

BRFSS Adverse Childhood Experiences (ACEs) Module

The BRFSS ACEs Module is an 11-item measure assessing different types of abuse, neglect, and household dysfunction.⁶¹ Caregivers were asked if they had experienced sexual, physical, or emotional abuse, witnessed intimate partner violence, observed substance use or mental illness in the household, experienced parental divorce, had an incarcerated family member, or experienced physical or emotional neglect before the age of 18. The measure is scored by summing all the items to create a total score that ranges from 0-11. Internal reliability for this measure was not calculated because participants could experience one ACE without necessarily experiencing another. The BRFSS ACEs module has demonstrated adequate validity for African American/Black samples.⁶²

Coddington Life Events Scale (CLES)

The CLES is a 45-item measure completed by children that is used to identify how positive and adverse life events may have affected their growth and adjustment.⁶³ A total adverse life events score is created by summing 17 items related to children’s experiences with death/illness of a loved one, divorce/separation of parents, parental loss of job/income, problems at school, substance abuse, experiencing/witnessing physical abuse, community violence, and parental incarceration. Responses are measured dichotomously with 0 = “No, this did not happen to me” and 1 = “Yes, this did happen to me.” Example items are “Did this ever happen to you: Death of a grandparent” and “Did this ever happen to you: Failing a grade in school.” The CLES has been identified as a valid measure for examining children’s adverse life events, including among African American/Black youth.⁶⁴ Internal reliability for this measure was not calculated because children could experience one of the adversities without necessarily experiencing another.

Alabama Parenting Questionnaire (APQ)

The APQ is a 42-item measure that assesses five dimensions of parenting including involvement, positive parenting, poor monitoring/supervision, inconsistent discipline, and corporal punishment.⁴² Each item is scored on a five-point Likert scale (never = 1, almost never = 2, sometimes = 3, often = 4, always = 5). The current study utilized the parental involvement subscale, which consists of 10 items. Both caregiver and child reports of parental involvement were included. Items on the two versions are identical, except that they are phrased to be from the child’s or caregiver’s perspective. An example item on the involvement subscale of the child version is “You play games or do other fun things with your parent.” For the caregiver version, this same item reads as “You play games or do other fun things with your child.” Reliability and validity of the APQ has previously been shown to be adequate for majority Black/African American samples.^{65,42} In the present study, Cronbach’s alpha was .84 for the caregiver involvement subscale and .80 for the child report of caregiver involvement.

Data analytic plan

Analyses were completed in SPSS v.29. Prior to running the primary analyses, the sample was screened for normality, outliers, missingness, and multicollinearity. There was no evidence of skewness or kurtosis (values under |2|). There was one outlier in the caregiver reported involvement subscale; it was removed prior to analysis. There was no evidence of multicollinearity (VIF < 2). Missing data was low, with 1.16% missingness across study measures. Given the low amount of missing data, mean imputation at the item level was used to address missingness. Two linear regression models were conducted, one child model and one caregiver model. The child model assessed the relations between the independent variables of child gender, child age, child adversity, and child report of caregiver involvement and the dependent variable of caregiver report of child’s externalizing problems. The caregiver model examined the relations between caregiver age, household income, caregiver ACEs, and caregiver report of caregiver involvement and the dependent variable of caregiver report of child’s externalizing problems.

RESULTS

Correlations and descriptive statistics for the continuous study variables are displayed in **Table 1**. For caregiver-reported child externalizing problems, the mean score was 55.06 (*SD* = 12.73; Range = 37-91), which falls in the average range of externalizing problems. Regarding caregiver ACEs, most caregivers reported experiencing at least one ACE (80.00%; *M* = 3.23, *SD* = 2.94; Range = 0-10). The most frequently reported types of caregiver ACEs were parental divorce/separation (55.38%), verbal abuse (46.15%), and household substance use (46.15%). All youth reported at least 2 adversities (*M* = 8.02, *SD* = 3.82; Range = 2-17). The most frequent types of child-reported adversities were death of a grandparent (56.92%), hospitalization of a parent (50.77%), and being hospitalized for an illness or injury (40.00%). For caregiver-reported involvement, the average score was 42.02 (*SD* = 5.47; Range = 28-50), while the average score for youth-reported caregiver involvement was 38.91 (*SD* = 8.24; Range = 17-50).

	1	2	3	4	5	6	7	8
1. Child Externalizing Problems	-							
2. Child Age	-.05	-						
3. Caregiver Age	.06	.23	-					
4. Household Income	-.10	.11	.09	-				
5. Caregiver ACEs	.36*	.08	-.004	.06	-			
6. Child Adversity	-.03	.18	.13	.05	.21	-		
7. Involvement (Caregiver report)	-.24	.17	.03	.003	-.09	.04	-	
8. Involvement (Child report)	-.19	.09	-.01	-.08	.06	-.01	.41**	-
<i>M</i>	55.06	9.15	36.20	3.06	3.23	8.02	42.02	38.91
<i>SD</i>	12.73	2.23	8.58	2.05	2.94	3.82	5.47	8.24

Table 1. Means, Standard Deviations, and Correlations Among Continuous Study Variables. **p* < .01, ***p* < .001; ACEs = Adverse Childhood Experiences

Results of the linear regression that included child-focused variables are detailed in **Table 2**. This model was not significant ($F(4, 58) = .93, p = .46, R^2 = .06$). Results of the linear regression that included caregiver-focused variables are provided in **Table 3** and show that the overall model was significant ($F(4, 58) = 3.31, p = .016, R^2 = .19$). In this model, caregiver ACEs were significantly related to child externalizing problems ($\beta = .34, sr = .34, p = .006$), such that more caregiver ACEs were associated with more child externalizing problems as reported by the caregiver. This finding supported hypothesis 1. None of the other independent variables were significantly related to externalizing problems in this sample (*p*'s > .05); thus, hypotheses 2-4 were not supported.

	β	<i>sr</i>	<i>t</i>	<i>R</i> ²	<i>F</i>
				.060	.926
Child Gender	-.15	-.15	-1.15		
Child Age	-.07	-.06	-.50		
Child Adversity	.03	.03	.20		
Involvement (Child)	-.14	-.14	-1.09		

Table 2. Linear Regression Model Examining Child Variables Associated with Children's Externalizing Problems.

	β	<i>sr</i>	<i>t</i>	<i>R</i> ²	<i>F</i>
				.19	3.31*
Caregiver Age	.07	.07	.60		
Caregiver Income	-.13	-.13	-1.07		
Caregiver ACEs	.34	.34	2.86*		
Involvement (Caregiver)	-.21	-.21	-1.73		

Table 3. Linear Regression Model Examining Caregiver Variables Associated with Children’s Externalizing Problems. **p* < .05; ACEs = Adverse Childhood Experiences

DISCUSSION

Previous research has examined how caregiver and child adversity are related to child externalizing problems; however, few studies have assessed parental involvement alongside adversities, and even fewer have included both child and caregiver report.^{26, 29} The current study, guided by Bowen’s Family Systems Theory, advanced the literature by examining polyvictimization and parental involvement concurrently, and included both caregivers’ and children’s experiences and perspectives. Such work provides unique insight into children’s functioning within the context of direct and intergenerational adversity while accounting for both youth and caregiver perspective on relevant parenting practices.

In line with the first hypothesis, more caregiver ACEs were significantly associated with more child externalizing problems, which is consistent with previous research.^{7, 8} Notably, this study adds to the literature as the sample consisted of majority Black or African American youth who have been historically understudied. This finding supports the concept of intergenerational transmission of risk; that is, caregiver ACEs have downward effects on the next generation’s functioning.⁷ Contrary to what was hypothesized, children’s own adversity was not significantly related to their externalizing problems, as assessed by their caregiver. This contrasts with what has been shown in past research.^{20, 21} Of note, the most common adversities experienced by youth in the current sample were hospitalization of themselves or a parent and death of a grandparent. It may be that these types of adversity are not as strongly related to externalizing problems as compared to adversities such as abuse and neglect, which were the focus of previous studies.¹⁹ Additionally, since the current study sample was help-seeking, it may be that youth and their families had more access to resources that promoted adaptive functioning following adversity.

Contrary to what was hypothesized, boys did not exhibit significantly more externalizing problems than girls, as reported by their caregivers. This finding is in line with some previous work that found no significant association between gender and externalizing problems, but does not align with a larger body of past research that has found a significant relation between these variables.^{50, 51} It may be that past work showing boys to exhibit more externalizing problems represents a perceived higher aggression in boys driven by bias concerning gender stereotypes, rather than an actual heightened manifestation of symptoms.⁴⁹ Also in contrast to the study’s hypotheses, both parent and child report of caregiver involvement were not significantly associated with child externalizing problems. Previous research has been inconclusive as to whether there is a significant association between caregiver involvement and decreased risk of children’s externalizing problems, with some studies identifying a negative relation between the two variables and others finding no association or an association only in one gender.^{40, 44} It may be that there is a stronger association between negative parenting practices (e.g., corporal punishment, inconsistent supervision) and externalizing problems, consistent with some past research.⁶⁵ Pearl and colleagues noted that the relationship between harsh parenting and externalizing problems is circular; for instance, conduct problems in the child at school may lead to harsher punishment from the caregiver.^{66, 67} That harsher punishment may, in turn, elicit more behavioral problems in the child. Additionally, Burlaka found no significant association between involvement and externalizing problems in children; however, this researcher did find a significant link between other forms of positive parenting and reduced externalizing behaviors.⁶⁵ Thus, it may be that involvement is not as strongly tied to externalizing problems in children as compared to other parenting practices, such as parental support or effective caregiver-youth communication.⁶⁸

Strengths

The current study has several strengths. First, participants primarily identified as Black or African American. Black families have received minimal attention in past research, particularly regarding identifying family strengths, so focusing on the experiences of

Black children and caregivers expands the literature on mutable factors impacting child behavior. Another strength is that the age range of youth was constrained to middle childhood (6-12 years), which allowed for the examination of youth during a unique developmental period. Previous research has shown that externalizing problems manifest differently based on developmental epoch,²² so focusing on one stage offers novel information. Next, the study included the perspective of both the caregiver and child, which is an advancement over previous work that examined only one individual's views. Finally, the study was theoretically grounded, which helped to guide our selection of variables and informed our hypothesized relations among those variables.

Limitations

There are notable limitations to the current study. The data were cross-sectional, which limits the interpretation of directionality and temporality between the variables. Data were also self-reported, which introduced potential for reporting bias. Additionally, the sample size was small ($n = 65$) which impacted power and limited the complexity of analyses that could be conducted. Another limitation is that the only aspect of parenting measured was parental involvement; there are other forms of parenting that could be considered in future studies (*e.g.*, corporal punishment, positive parenting).⁸ The way in which caregiver adversity was measured is another limitation of the study. Caregiver ACEs were measured dichotomously (*i.e.*, whether an event happened), which does not allow for the evaluation of frequency or severity of the events. Additionally, caregiver adversity was examined only in childhood, so the current study did not account for adversity exposure across the caregiver's lifespan. Most notably, this study did not have access to a child report of the child's own externalizing problems, which is a significant limitation because there is a need to examine how youth view their own functioning and behavior.

Future directions

Future research should explore variables that may explain the intergenerational link identified in this study, such as other positive and negative parenting practices or parent-child relationship factors (*e.g.*, communication, attachment). Additionally, future research should examine caregiver and child adversity and parental involvement longitudinally to enhance understanding of the direction of relations between variables, including any mediating or moderating pathways. Further, future research should account for potential protective factors that may mitigate externalizing problems in youth exposed to adversity, such as resilience or close peer and familial relationships.⁶⁹ Evaluating protective factors in addition to adversity variables would enhance future research by providing opportunities to better understand how strengths within youth and families can promote positive functioning even in the context of adversity.⁷⁰ Future research should also include an examination of the frequency and severity of caregiver ACEs, as well as measuring caregiver adversities across the lifespan. The current study highlighted the utility of including multiple informants, so future research should continue to do so, and include other potential informants, such as teachers, coaches, or mentors. Future studies should assess youth's own perception of their functioning and specifically include child-report on their own externalizing behaviors. The inclusion of different types of measures other than self-report, such as lab-based observational tasks, could also provide a more comprehensive assessment of child functioning and parenting practices.

Clinical implications

Results from this study demonstrate the importance of considering multiple factors and perspectives when assessing and treating youth's psychological functioning. This is especially important in Black and African American families who often experience disparities in health care, including a relative lack of culturally responsive care and higher rates of stigma.⁷⁰ Study findings highlight the impact of parental adversity on youth functioning, indicating that more than just the child's own adversity needs to be considered when developing a comprehensive treatment plan. Thus, providers treating youth with externalizing problems should assess caregiver's history of adversity and how experiencing ACEs may affect their parenting as well as their child's functioning. Future intervention efforts should examine past familial adversities from multiple perspectives when treating externalizing problems in children. Study findings also partially support Bowen's Family Systems Theory and underscore the value of examining multiple perspectives and experiences within the family system, which shows the need to include multiple viewpoints and consider family therapy when developing treatment plans for youth experiencing externalizing problems.

CONCLUSIONS

The current study took an intergenerational, theoretically grounded, and multi-informant approach to examine how individual, familial, and adversity related factors were linked to child externalizing problems. Findings showed that caregiver's history of ACEs was associated with externalizing problems in children. This study makes valuable contributions to the child psychopathology literature by examining variables concurrently that have been previously studied separately, and by using both caregiver and child report. Knowledge gained from this study may be used to develop more effective interventions for youth displaying maladaptive functioning.

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PRESS SUMMARY

Previous studies have shown that exposure to adverse childhood experiences (ACEs) is associated with increased behavioral problems in children. Notably, past research has rarely explored both the child's and caregiver's ACEs exposure. The current study examined how individual, familial, and adversity related variables contribute to children's externalizing problems using information provided by both the child and their caregiver. Results showed the intergenerational impact of caregiver ACE history on child functioning, with more caregiver ACEs related to higher externalizing problems in children. Mental health professionals should consider incorporating an assessment of caregiver adversity history when developing treatment plans for youth experiencing externalizing problems.

Cross-validation Optimal Fold-Number for Model Selection

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ABSTRACT

The resampling method of k -fold cross-validation is popular for error estimation and model selection in computational research. However, there is limited focus in the literature on the question of what fold number k is appropriate for various dataset dimensions. Here we review relevant literature and present a simulation of linear and least absolute shrinkage and selection operator (LASSO) regression prediction error estimation at various values of k and sample size n . In agreement with current literature, we find that contrary to a persisting understanding, there is no bias-variance trade-off in selection of k . Instead, with increasing k both bias and variance decrease, perhaps asymptotically. Our results also suggest a predictable relationship between optimal values of k and n .

KEYWORDS

Cross-validation; Optimization; Fold number

INTRODUCTION

Cross-validation, also known as k -fold cross-validation, is a popular method of error estimation for model selection in computational research. In this method, n observations are first divided into k groups. In a first iteration, $k - 1$ groups are used as a training set. The remaining group is used as a test set to calculate estimated prediction error ($\widehat{\text{PE}}$). This process is repeated i times, with a different test set in each iteration. The average of k estimates of PE

$$\hat{\theta} = CV_{(k)} = \frac{1}{k} \sum_{i=1}^k \widehat{\text{PE}}_i \quad \text{Equation 1.}$$

is meant to estimate the true model error θ , i.e., the error of the model tested on the population.¹ When the objective is to choose a best-performing model of a set, $CV_{(k)}$ is calculated for each candidate model and the model with the lowest CV_k is usually selected.

Despite the popularity of cross-validation, there is limited focus in the literature on the question of what fold number k is appropriate for cross-validation with a dataset of a given size. One popular idea is that selection of k comes with a bias-variance trade-off—specifically, that as k increases, the bias $Bias(\hat{\theta}) = E(\hat{\theta}) - \theta$ and variance $Var(\hat{\theta}) = E(\hat{\theta}^2) - E(\hat{\theta})^2$ of k -fold error estimation decrease and increase, respectively. This idea appears in early literature but also in modern, widely used textbooks.^{4, 5, 7} If the idea that the choice of k is associated with bias and variance, via a bias-variance trade-off or differently, is true, then the selection of k can drastically influence model performance and selection.

Subsequent, albeit limited, literature argues differently. In the case of leave-one-out cross-validation (LOOCV), i.e., with $k = n$, some authors suggest that asymptotically both bias and variance of error estimation decrease as k increases and that bias and variance of error estimation are uniformly low.^{9, 10}

More recently, different ways have been proposed to quantify the variance reduction achieved by cross-validation when the true prediction error (PE) is not known, e.g., as mean-square stability or as loss stability.^{11, 12} However, it has also been demonstrated that, due to overlap between training and test sets in cross-validation, there is no universal (i.e., valid under all distributions) unbiased estimator of the variance of k -fold cross-validation.¹³

In addition to theoretical analyses, there are some simulation results showing the phenomenon of variance reduction by cross-validation. However, simulations currently in the literature provide limited insight into the dependence of optimal fold number k_{optimal} on sample size n or involve biased variance calculations.^{14, 15} Here we present a simulation of linear regression and least absolute shrinkage and selection operator (LASSO) regression to observe the relationship of cross-validation fold number k to model selection accuracy for various samples of size n under the assumptions of linear regression.¹⁹ Our focus is a known population with a feature Y of the form $Y = \beta_0 + \beta_1 X_1 + \dots + \beta_5 X_5 + \epsilon$ where $\beta_1 = \dots = \beta_5 = 1$, $\epsilon \sim N(0, 10)$, and mean squared error (MSE) is the loss function.

METHODS AND PROCEDURES

In machine learning tasks, the values of 5 and 10 traditionally have been used as the values of k in k -fold cross validation and here we evaluate these choices and alternatives.²⁰ With the results of the following simulation, we make a different recommendation of k with the aim of improving model selection accuracy.

Population

Consider a population of size $N = 500,000$ with five of $P = 100$ features $X_1 \dots X_{100} \sim N(0, 1)$ a linear combination of feature $Y = \beta_0 + \beta_1 X_1 + \dots + \beta_5 X_5 + \epsilon$ where $\beta_1 = \dots = \beta_5 = 1$ and $\epsilon \sim N(0, 10)$. The true model of Y is $f \in F$, a set of competing models. $f = E(Y) = \beta_0 + \beta_1 X_1 + \dots + \beta_5 X_5$ and its MSE is

$$\theta = \text{MSE}(f) = \frac{\sum_{i=1}^N [Y_i - E(Y_i)]^2}{N} \tag{Equation 2.}$$

Sampling and regression

From the population we take a sample of size n . We estimate Y as \hat{Y} by regression on a subset of $X_1 \dots X_{100}$, regression coefficients estimated by the least squares method, and compute $\text{MSE}(\hat{Y})$ by k -fold cross-validation as

$$\hat{\theta} = \text{MSE}(\hat{Y}) = \frac{1}{k} \sum_{j=1}^k \frac{\sum_{i=1}^{n/k} (Y_{j_i} - \hat{Y}_{j_i})^2}{n/k} \tag{Equation 3.}$$

where j_i is the index of the i^{th} element of the j^{th} fold.

In addition to regression with $X_1 \dots X_5$, f , we under-fit with $X_1 \dots X_3$, over-fit with $X_1 \dots X_{20}$ and $X_1 \dots X_{100}$, and do regression with noise $X_6 \dots X_{100}$ only, for each $k \in 2, 10, 20, 30, \dots, n$ for each $n \in 100, 200, 300, \dots, 1000$.

Simulation

We perform this simulation 1000 times and then calculate simulation-wise $\text{MSE}(\hat{\theta})$ for each k , for each n .

We perform an additional 1000 simulations predicting Y as \hat{Y} by LASSO regression instead of linear regression for each $k \in 2, 10, 20, 30, \dots, 100$, n for each $n \in 250, 500, 750, 1000$. To avoid data leakage, in which testing data is used in model training^{2, 3}, we introduce an inner 5-fold cross-validation loop for the selection of parameter λ as in the minimization of

$$\sum_{i=j}^p (Y_j - \beta_j)^2 + \lambda \sum_{j=1}^p |\beta_j|. \tag{Equation 4.}$$

For each k , for each n , we count the number of times A that the true model is selected and consider as optimal fold number for each n the value k_{optimal} , at which A is the highest.

This is because in practice the model with the lowest \widehat{PE} is more likely to be selected.¹⁶ We refer to this as lowest-error model selection. As our simulation results show, however, it is possible for k -fold cross-validation to result in calculations of $MSE(\hat{\theta})$ such that a competing model $\hat{f} \in F$ has a lower \widehat{PE} than the true model f . This false model may have the lowest \widehat{PE} but its generalization error will be higher in the long-run (i.e., when tested on a large part of the population) than the generalization error of the true model. Thus, it is preferable for the value of k selected to result in f having the lowest \widehat{PE} .

Fold number as a function of sample size

Having considered the effect of k on model selection accuracy for a given n , we may also consider the relationship of k_{optimal} and n . Our results suggest that after a certain value of k , changes in A become negligible, in the case of linear regression, or negative, in the case of LASSO regression, and resource-expensive increases of fold number become undesirable. We refer to this "point of diminishing returns" as k_{optimal}^* using the "elbow method" commonly used in cluster analysis.¹⁷

To estimate k_{optimal}^* for each n , we first fit to the dataset (k, A) for each sample size n a hypothetical model of the form

$$\hat{A}(k) = Bk + C + \frac{D}{k} \tag{Equation 5.}$$

with constants B to D specific to each n . Certain more complicated models (e.g., with higher-order terms) may provide better approximation of A but make optimization by the following scheme non-trivial. We draw a line L through (k_1, \hat{A}_1) and (k_n, \hat{A}_n) and maximize the perpendicular distance d of each point on \hat{A} from L , so that

$$\begin{aligned} k_{\text{optimal}}^* &= \arg \max_k d[\hat{A}(k), L] \\ &= \arg \max_k d[Bk + C + \frac{D}{k}, y - (Bn + C + \frac{D}{n}) = m(x - n)] \\ &= \arg \max_k d[Bk + C + \frac{D}{k}, y - (Bn + C + \frac{D}{n}) = \frac{(Bn + C + \frac{D}{n}) - (2B + C + \frac{D}{2})(x - n)}{n - 2}] \\ &= \arg \max_k d[Bk + C + \frac{D}{k}, y - (Bn + C + \frac{D}{n}) = (B - \frac{D}{2n})(x - n)] \\ &= \arg \max_k d[Bk + C + \frac{D}{k}, (B - \frac{D}{2n})x - y + C + \frac{D}{2} + \frac{D}{n} = 0] \end{aligned} \tag{Equation 6.}$$

It is known that the distance d between a point $(k, \hat{A}(k))$ and a line of the form

$$ax + by + c = 0 \tag{Equation 7.}$$

is

$$d = \frac{|ak + b\hat{A}(k) + c|}{\sqrt{a^2 + b^2}} \tag{Equation 8.}$$

so

$$\begin{aligned} k_{\text{optimal}}^* &= \arg \max_k d[Bk + C + \frac{D}{k}, (B - \frac{D}{2n})x - y + C + \frac{D}{2} + \frac{D}{n} = 0] \\ &= \arg \max_k \frac{|(B - \frac{D}{2n})k - (Bk + C + \frac{D}{k}) + (C + \frac{D}{2} + \frac{D}{n})|}{\sqrt{(B - \frac{D}{2n})^2 + (-1)^2}}. \end{aligned} \tag{Equation 9.}$$

Maximizing d , knowing that n and k are always positive, we find that

$$\begin{aligned} \frac{d}{dk}d[\hat{A}(k), L] &= \frac{d}{dk} \left(\frac{|(B - \frac{D}{2n})k - (Bk + C + \frac{D}{k}) + (C + \frac{D}{2} + \frac{D}{n})|}{\sqrt{(B - \frac{D}{2n})^2 + (-1)^2}} \right) \\ &= \frac{|n||k|(2nD - Dk^2)(-Dk^2 - 2nD + nDk + 2Dk)}{nk^3| - Dk^2 - 2nD + nDk + 2Dk|\sqrt{D^2 + 4n^2}} = 0 \\ &\Rightarrow k = 0, 2, \sqrt{2n}, n. \end{aligned} \tag{Equation 10.}$$

Evaluating d at these four values of k , we find that

$$\begin{aligned} d(0) &= \text{DNE} \\ d(2) &= 0 \\ d(\sqrt{2n}) &= \frac{|nD + 2D - \sqrt{2n}D - D|}{\sqrt{(B - \frac{D}{2n})^2 + (-1)^2}} \\ d(n) &= 0. \end{aligned} \tag{Equation 11.}$$

Since $d(\sqrt{2n}) > 0$,

$$k_{\text{optimal}}^* = \sqrt{2n} \tag{Equation 12.}$$

which fits the relationship of k_{optimal}^* vs. n (Figure 9).

A note on LASSO

It may seem that the choice of $k = 5$ for the selection of λ by cross-validation is presumptive for a study that seeks to determine the best value of k for cross-validation. If the choice of k influences the value of λ , it influences the subset of models that will be competing with f . Does k_{optimal}^* change with the subset of models competing with f ? Replications of this simulation varying k only in the selection of λ may elucidate.

RESULTS AND DISCUSSION

Interpretations of early literature have resulted in lasting misconceptions about the use of cross-validation. Such misconceptions include the idea that there is a bias-variance trade-off $Bias^2(\hat{\theta}) \propto 1/Var(\hat{\theta})$ associated with selection of k and that $k = 10$ is the best value to use in k -fold cross-validation.⁵⁻⁸

In agreement with a small but growing body of literature, our simulation results suggest that neither of these ideas are necessarily correct. Instead, in the context of linear and LASSO regression with standard normal data and certain random error, we find that for various n both bias and variance decrease as k increases (Figures 1 - 6), i.e., $Bias^2(\hat{\theta}) \propto Var(\hat{\theta})$, and although in the case of LASSO, 10-fold cross-validation seems to be a near-optimal choice for large n , for smaller samples and linear regression other values of k appear to be optimal for model selection (Figures 7 and 8; Table 1).

Table 1. Optimal values of k for sample sizes n in linear regression.

n	100	200	300	400	500	600	700	800	900	1000
Optimal k	14	20	25	28	32	35	37	40	42	45

Table 2. Optimal values of k for sample sizes n in LASSO regression.

n	100	250	500	750	1000
Optimal k	14	22	32	39	45

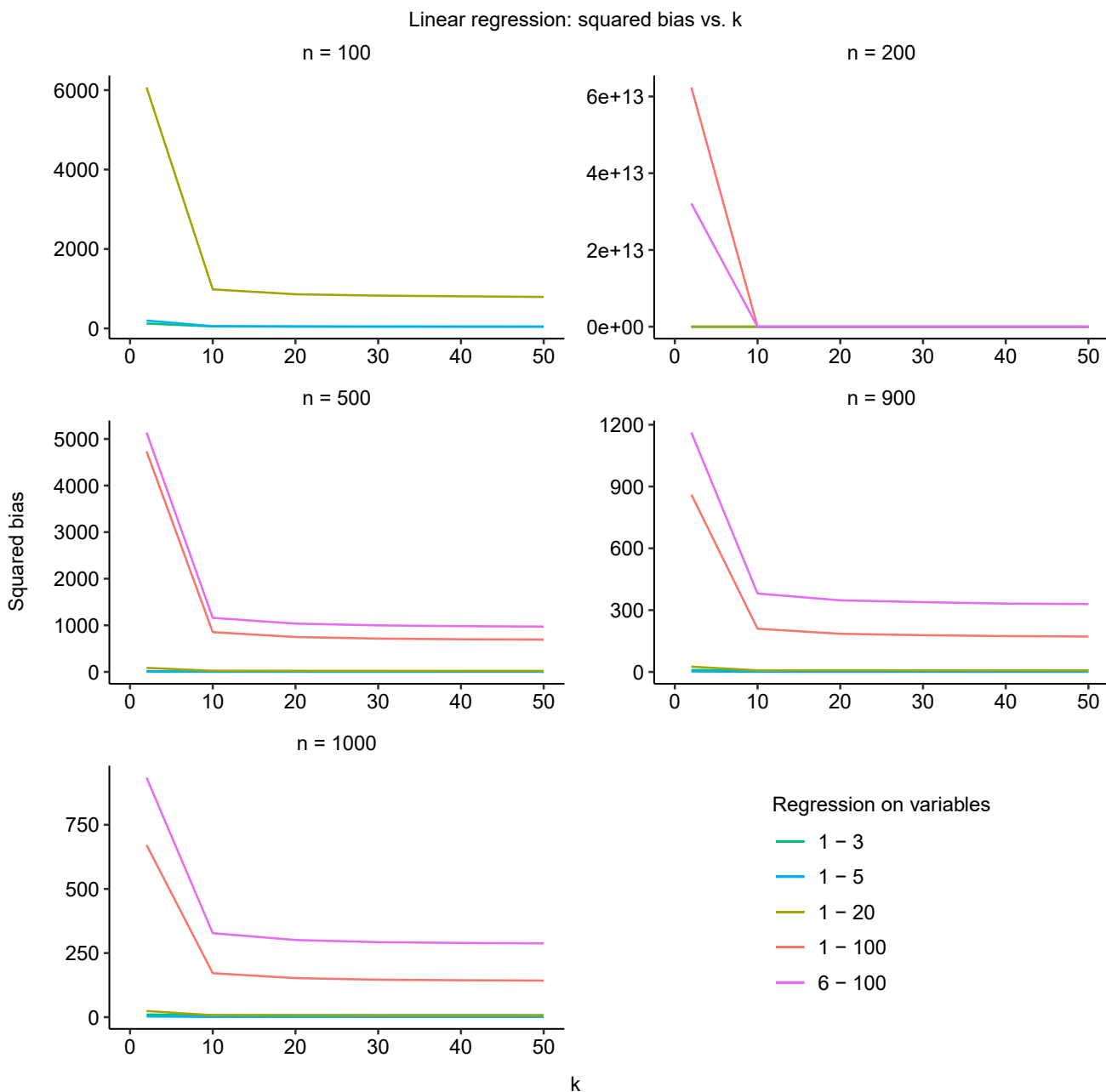


Figure 1. Linear regression squared bias vs. fold number for various sample sizes. As fold number increases, bias decreases initially before leveling off. See Figure 10 in appendix for more sample sizes and fold numbers over 50.

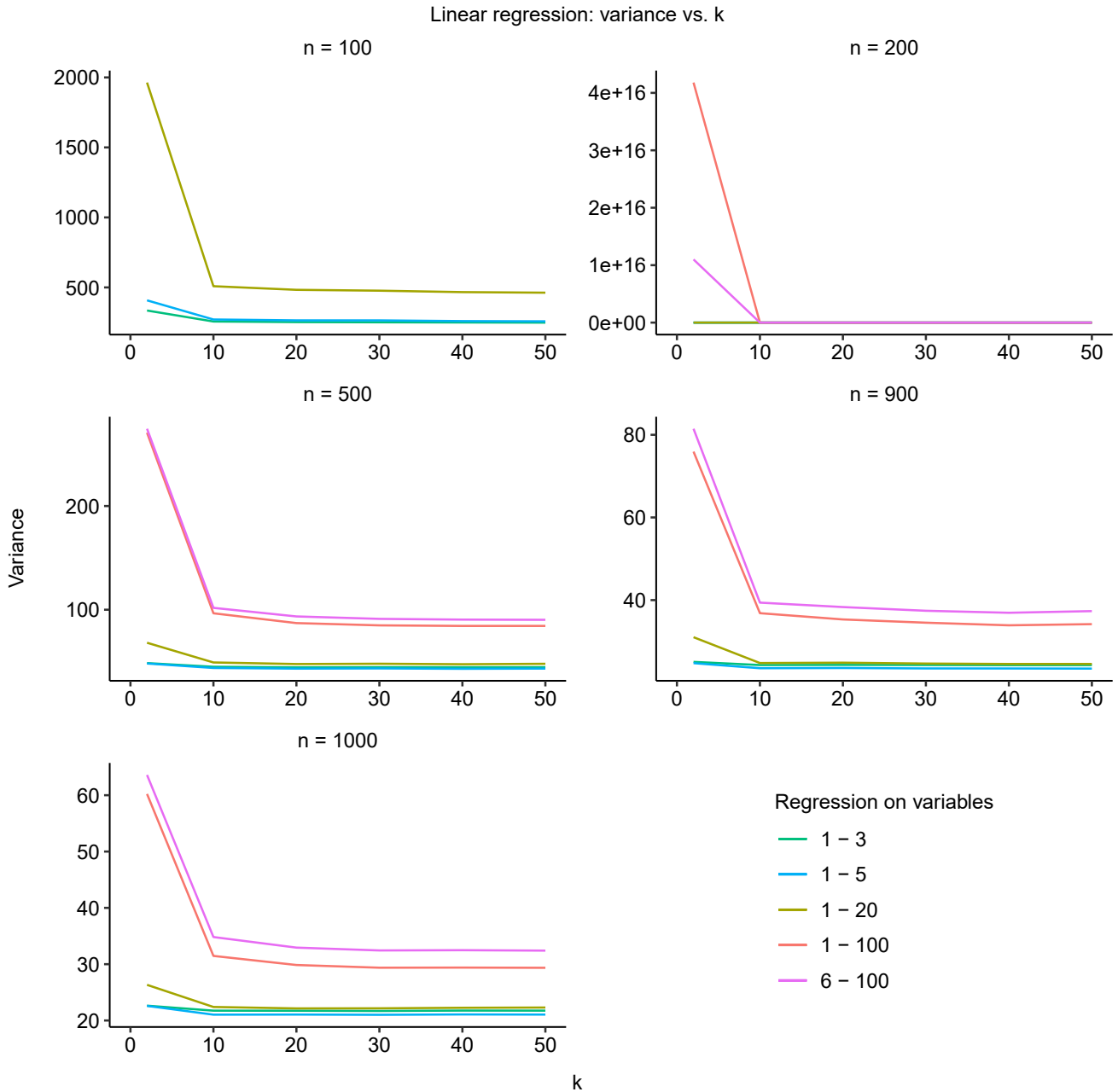


Figure 2. Linear regression variance vs. fold number for various sample sizes. As fold number increases, variance decreases initially before leveling off. See Figure 11 in appendix for more sample sizes and fold numbers over 50.

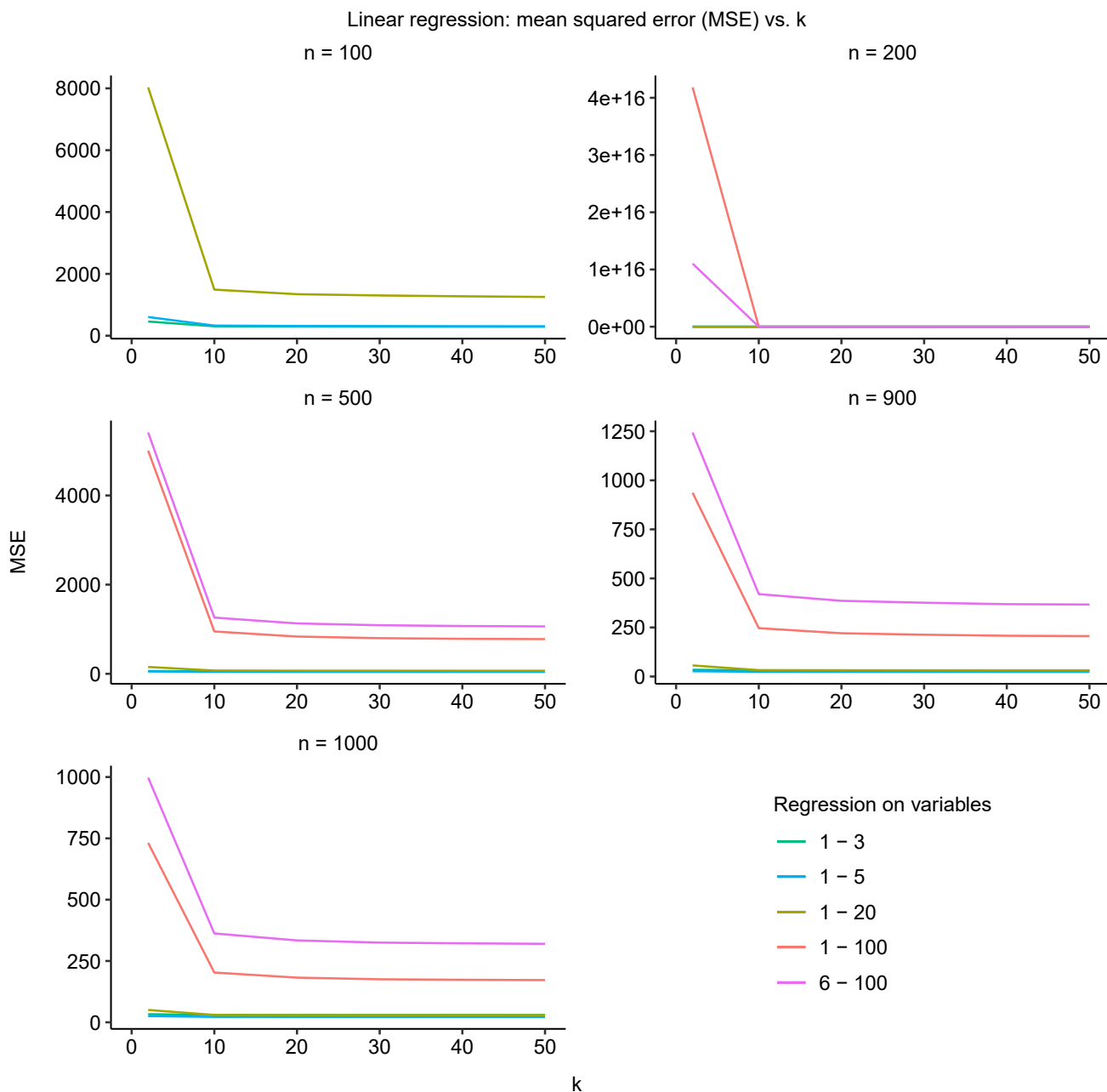


Figure 3. Linear regression mean squared error vs. fold number for various sample sizes. As fold number increases, mean squared error decreases initially before leveling off. See Figure 12 in appendix for more sample sizes and fold numbers over 50.

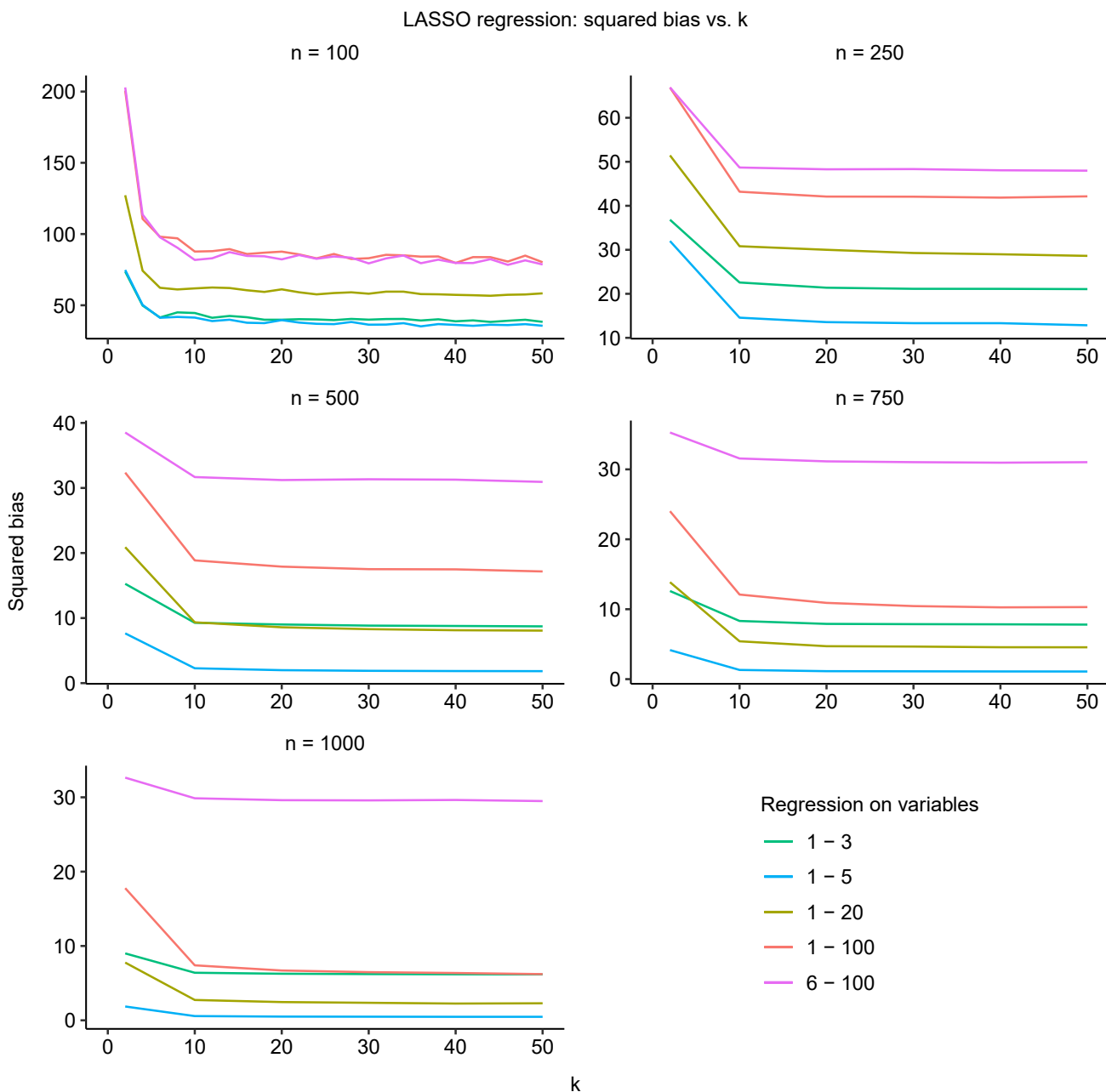


Figure 4. Linear regression squared bias vs. fold number for various sample sizes. As fold number increases, bias decreases initially before leveling off. See Figure 13 in appendix for fold numbers over 50.

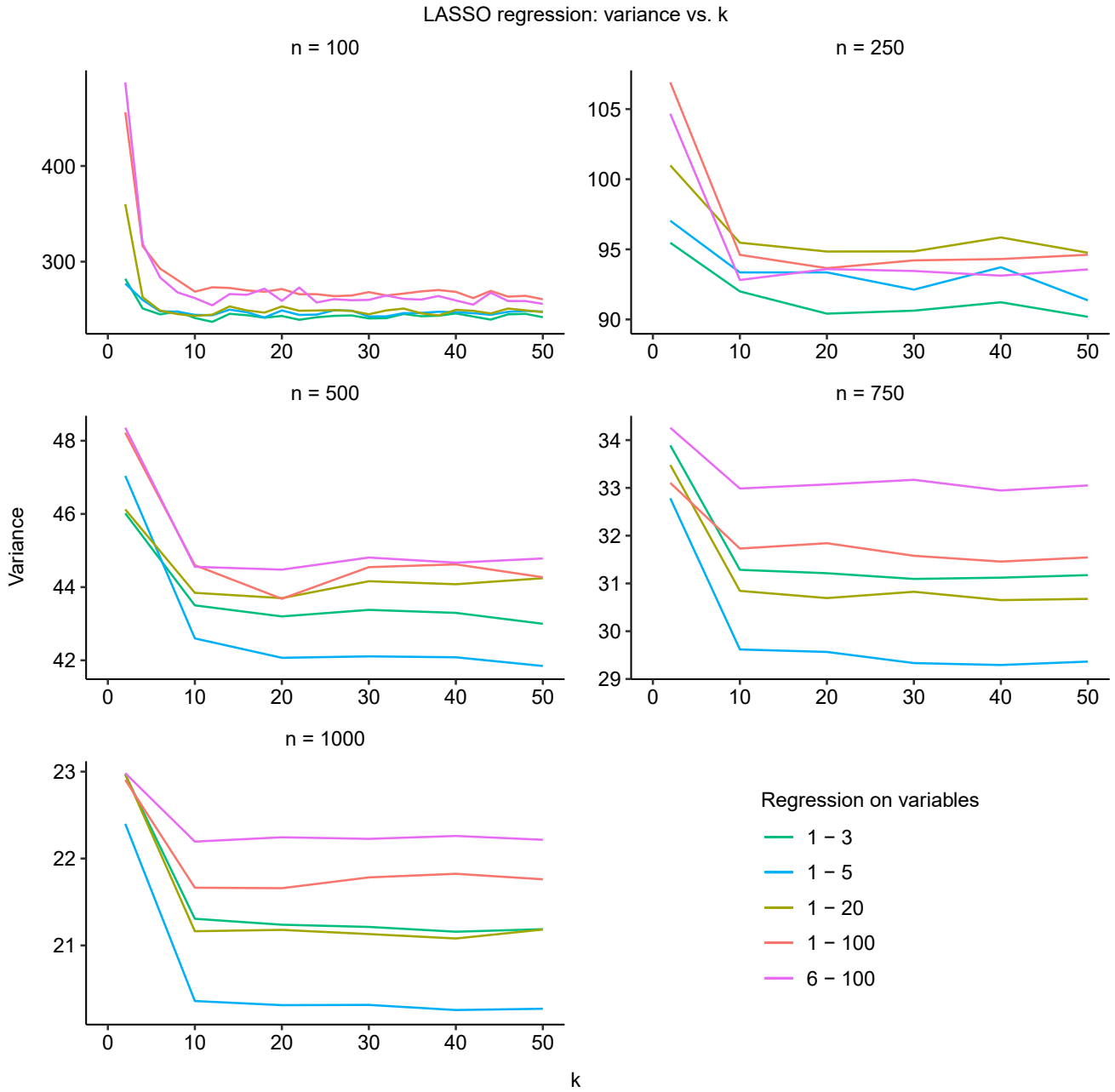


Figure 5. LASSO regression variance vs. fold number for various sample sizes. As fold number increases, variance decreases initially before leveling off. See Figure 14 in appendix for fold numbers over 50.

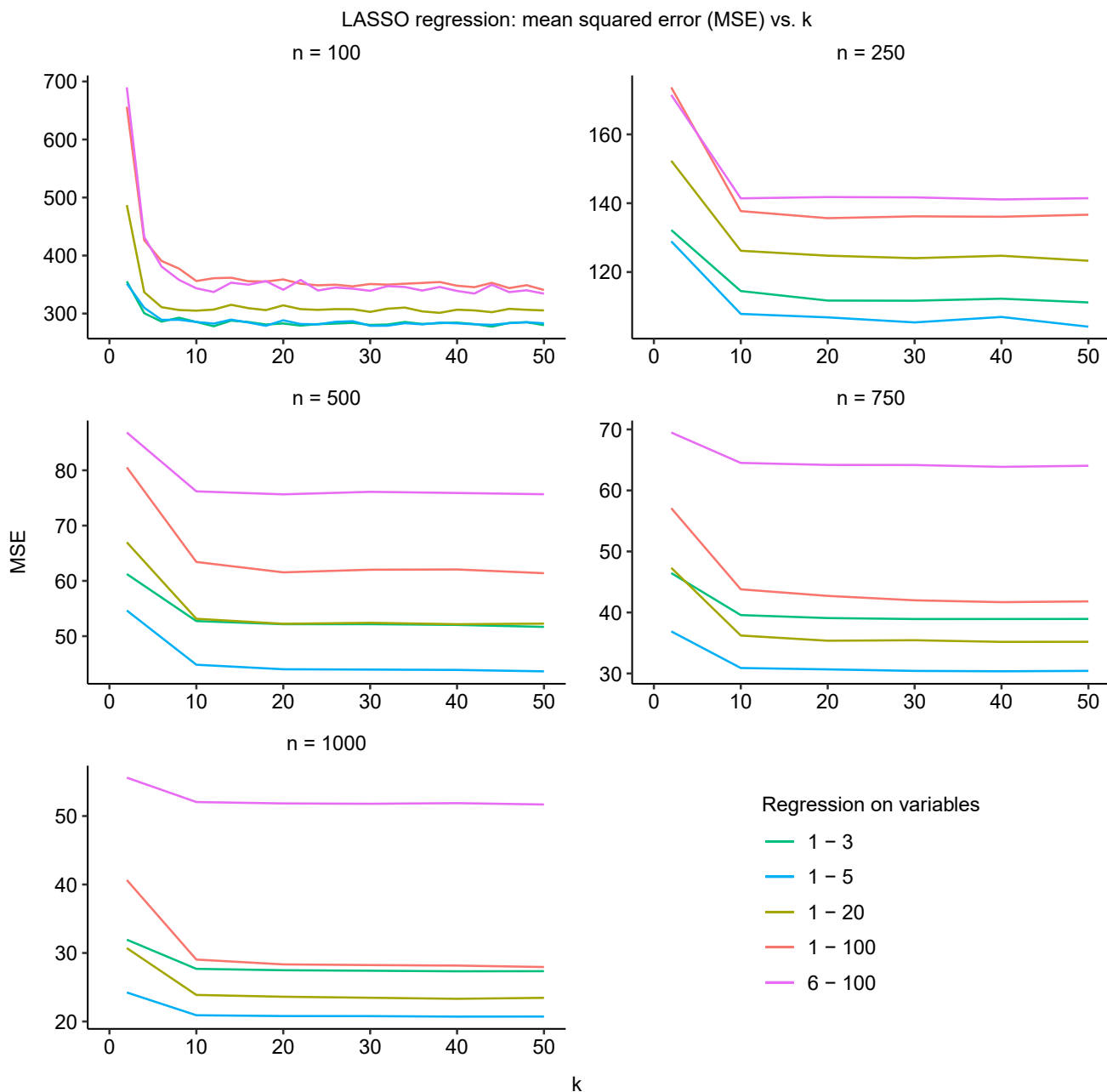


Figure 6. LASSO regression mean squared error vs. fold number for various sample sizes. As fold number increases, mean squared error decreases initially before leveling off. See Figure 15 in appendix for fold numbers over 50.

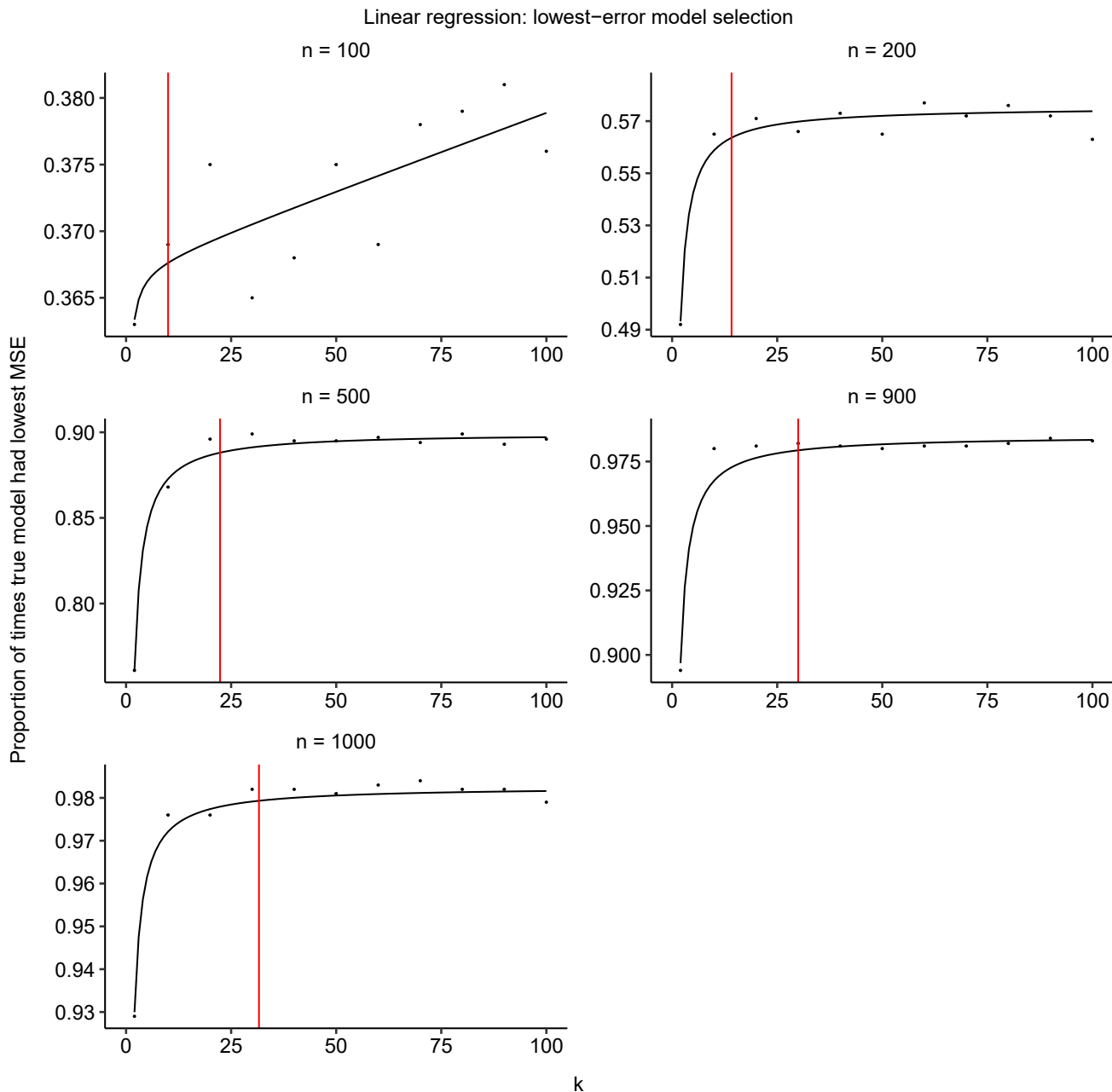


Figure 7. For linear regression, the proportion of times the true model has the lowest mean squared error *vs.* fold number for various sample sizes. As fold number increases, the proportion of times that the true model is selected increases, but the rate of this increase declines. See Figure 16 in appendix for fold numbers over 100 and more sample sizes.

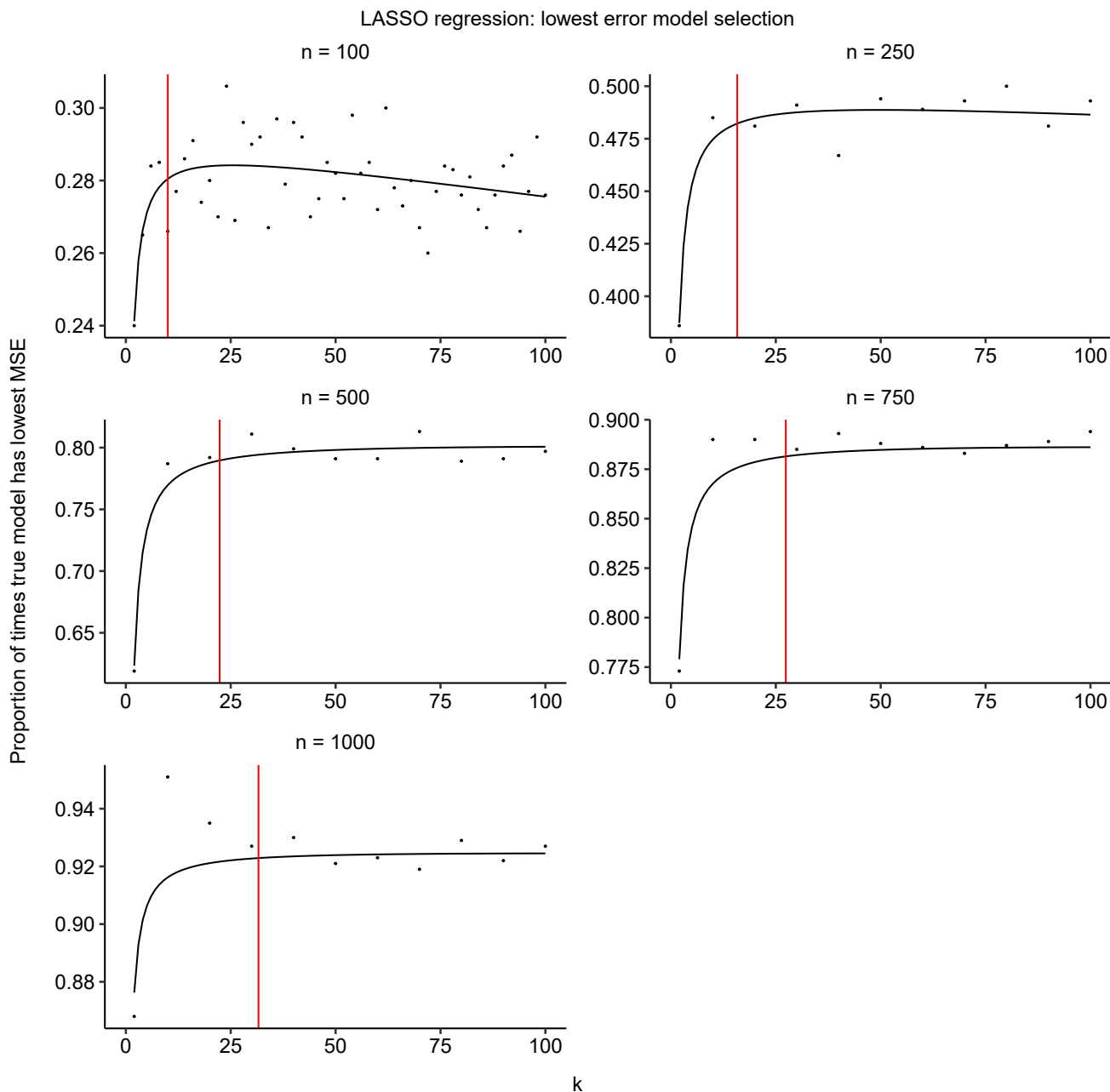


Figure 8. For LASSO regression, the proportion of times the true model has the lowest mean squared error *vs.* fold number for various sample sizes. As fold number increases, the proportion of times that the true model is selected increases, but the rate of this increase declines. See Figure 17 in appendix for fold numbers over 100 and more sample sizes.

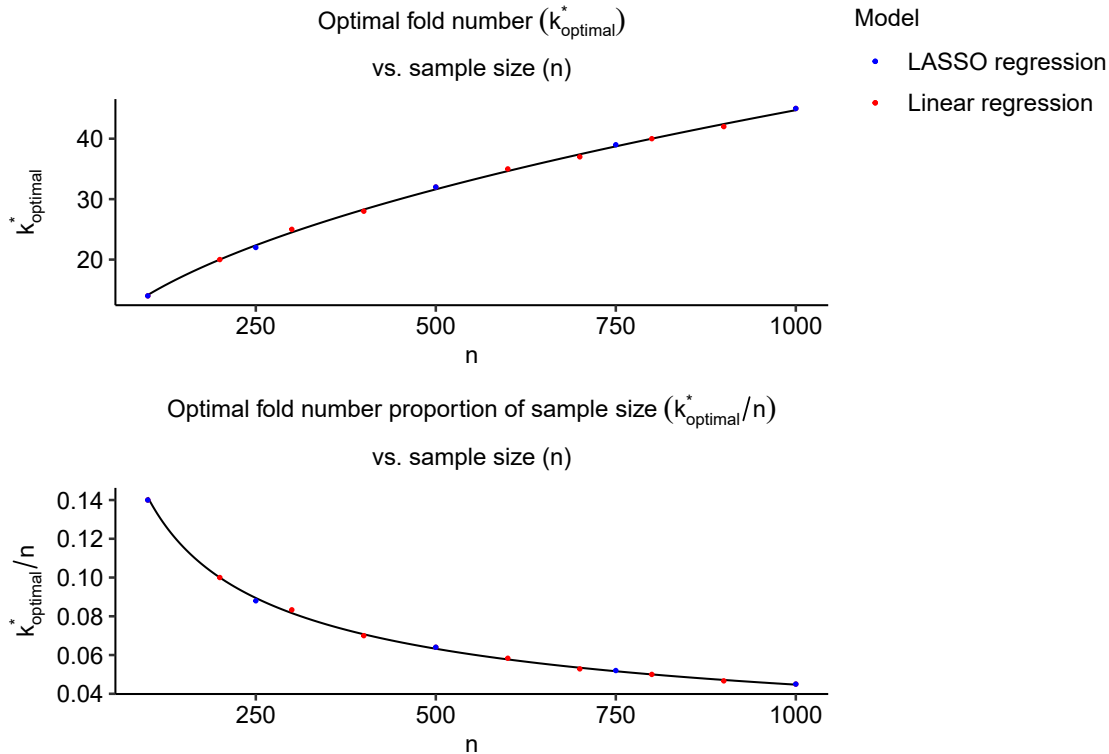


Figure 9. Sample size vs. fold number. As sample size increases, optimal fold number increases at a diminishing rate.

Note that the case of linear regression with $n = 100$ and number of features $p = 100$ is not displayed because there are $n - p - 1 = -1$ degrees of freedom, which is not a sufficient number for regression. The case of $n = 100$ and $p = 95$ degrees of freedom is similarly problematic and is not displayed because the high level of error in bias, variance, and MSE estimation associated with $n - p - 1 = 5$ degrees of freedom obscures important patterns in the rest of the data.

As previous authors have noted,¹⁴ it is important to distinguish between possible goals of cross-validation that previously have been conflated⁵: estimation of PE, in which case $k_{\text{optimal}} = \arg \min_k (\text{PE} - \widehat{\text{PE}})$, and model selection, in which case

$$k_{\text{optimal}} = \arg \max_k (A) \tag{Equation 13.}$$

which is related to the definition of k_{optimal}^* used in this study.

We find that in the cases of both linear and LASSO regression, as n increases, k_{optimal}^* increases but at a lower rate than n , such that k_{optimal}^*/n decreases, perhaps asymptotically. For LASSO regression, we also find that as k increases past a certain value, lowest-error model selection becomes less reliable, i.e., \hat{A} decreases, i.e., the true model has the lowest MSE less frequently (Figure 8). The rate of this reduction increases with n .

The reason for this is related to what is known as the cross-validation paradox¹⁸: greater quantity of data results in more accurate estimation of PE; occasionally, this makes model-wise differences in $\widehat{\text{PE}} = CV_{(k)}$ less exaggerated, making it more difficult to distinguish between models and resulting in less accurate model selection.

However, we do not observe the cross-validation paradox in our linear regression simulations. Although cross-validation results in similar bias-variance reductions in both cases, in the case of linear regression \hat{A} increases with increasing k initially before leveling off. However, this is not surprising, as our linear regression simulation does not involve variable selection, so that the differences in models are more pronounced. To observe the cross-validation paradox in linear regression would require comparison of more similar linear models predisposed to similarity in $\widehat{\text{PE}}$, as in the simulation

of LASSO regression.

In the cases of both linear and LASSO regression, k_{optimal}^*/n seems to change predictably with n . Specifically, it may be possible to model the relationship with some asymptotically decreasing function, while the relationship between k_{optimal}^* and n seems to follow a positive pattern (Figures 9 and 10).

CONCLUSIONS

Early literature suggests that increasing cross-validation fold number is related to decreasing bias and increasing variance of error estimation. However, more recent work suggests that this is not the case. Instead, increasing k results in bias and variance reduction. This phenomenon is observable in our simulation results, which suggest that bias and variance decrease asymptotically with increasing k .

Our results also indicate a predictable relationship between k_{optimal}^* and sample size n . Although further data and analysis are needed to draw any reliable conclusions, modeling the relationship between n and k_{optimal}^* would have practical utility, potentially improving the selection of k from a largely arbitrary decision between 5 and 10.

Future research may also focus on error estimation of other models, including models capturing non-linear relationships or involving tuning of multiple hyper-parameters, e.g., random forest or gradient boosting. It may also be interesting to study the value of k in repeated cross-validation or nested cross-validation, with the value of k variable in the inner loop, outer loop, or both, as the use of $k = 5$ for the selection of λ in this simulation is a notable limitation of the study.

Comparisons of k -fold cross-validation and other model selection tools like the Akaike information criterion (AIC), the Bayesian information criterion (BIC), and forward or backward selection are also of interest.

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PRESS SUMMARY

In the field of data science, k -fold cross-validation is a popular method for estimating model error and selecting optimal models. It involves splitting a dataset into k parts, or folds, training a model on each of those parts, and averaging the models' respective errors as an estimate of "true" model error. What has received limited attention in the literature is the following question: what is the optimal number of parts to split a dataset into for the purposes of error estimation and model selection? Here we explore this question and simulate the results of different fold number selections in two different model settings. We suggest that there may be a predictable relationship between optimal values of k and n .

Effects Of Sex Education Perspectives

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ABSTRACT

Sex education is crucial for promoting informed and healthy sexual behaviors, though the content and approach of these programs have varied significantly. This study examined three distinct approaches to sex education—love and intimacy-based, biology-based, and abstinence-based—with the aim of evaluating how each influenced perceptions of sex, virginity, love, intimacy, and sexual well-being. By examining the strengths and limitations of these strategies, this research aims to enhance the investigation of diverse sex education perspectives. Participants were randomly assigned to one of four groups: love and intimacy-based, biology-based, abstinence-based, or control, with each group receiving a corresponding educational video, except for the control group. Although no statistically significant differences were observed among the groups, participants who already held abstinence-based perspectives were more likely to view virginity as a gift. Significant gender differences were also found, with women reporting higher levels of stigma and stronger associations of love with sex. These findings underscored the impact of participants' preexisting sex education perspectives and gender on their attitudes toward sex and virginity, suggesting that sex education programs may benefit from accounting for these individual differences to enhance their effectiveness.

KEYWORDS

Sex Education; Comprehensive Sex Education; Abstinence-Based Sex Education; Love And Intimacy-Based Sex Education; Biology-Based Sex Education; Sexual Well-Being; Perceptions Of Virginity; Gender Differences; Sexual Attitudes

INTRODUCTION

Sex education plays a crucial role in fostering informed attitudes and behaviors toward sexuality, yet the effectiveness of various programs continues to be a topic of debate. Many sex education programs still do not offer comprehensive approaches that meet the diverse needs of individuals, leaving gaps in knowledge about sexual health, emotional intimacy, and relationship dynamics. These limitations ultimately impact individuals' ability to make knowledgeable decisions about their sexual lives.¹

Implementing comprehensive sex education programs is crucial for fostering a healthy understanding of sexuality and promoting overall sexual well-being. Comprehensive sex education refers to programs that not only cover the biological aspects of sex, such as reproduction and contraception, but also explore emotional, relational, and ethical dimensions. This includes topics like consent, relationships, communication, and decision-making, offering individuals a more holistic approach to sexual health. Sexual well-being, which encompasses aspects of sexual activity, partner satisfaction, and quality of life, plays an integral role in shaping individuals' sexual experiences.² These programs address not only biological aspects of sex but also emotional, relational, and ethical dimensions, offering a more holistic approach. In contrast, abstinence-only or purely biology-based programs can leave significant gaps in understanding. Comprehensive sex education has been shown to improve sexual well-being, enhance relationship satisfaction, and boost overall quality of life, though outcomes may vary based on individual context and prior knowledge.³ Additionally, such programs have demonstrated effectiveness in delaying the onset of sexual activity, reducing the number of sexual partners, increasing contraceptive use, and lowering the incidence of STDs and unintended pregnancies.^{4,5} These findings underscore the benefits of comprehensive education, which abstinence-only approaches often fail to match.⁶

Conversely, the absence of comprehensive sex education leaves individuals vulnerable to the consequences of uninformed decisions. Without access to vital information, individuals may lack the knowledge and skills to effectively manage sexual health, which can lead to unintended outcomes such as unplanned pregnancies or the spread of STDs.⁷ Recent legislative developments, particularly those restricting abortion rights, have further complicated access to reproductive health services.⁸ These changes have contributed to an increase in unplanned pregnancies among teens and young women, underscoring the need for broader access to

reproductive knowledge and comprehensive educational programs.⁹ Advocacy groups and educators continue to push for comprehensive sex education in schools to address these gaps in knowledge and promote healthier sexual behaviors.¹⁰

A key issue contributing to the ongoing debate about sex education is the inconsistency in curricula across different states and school systems, which has resulted in varying levels of knowledge and preparedness among students.⁷ Many states still prioritize abstinence-only programs, which are often rooted in fear-based messaging. These programs have consistently failed to delay sexual activity or reduce risky sexual behaviors, yet they remain prevalent due to persistent beliefs that discussing sex might promote harmful behavior.³ Recent legislative restrictions on sexual and reproductive health access further underscore the need for standardized, inclusive sex education programs that provide accurate, evidence-based information.⁹ Despite evidence showing the ineffectiveness of abstinence-only education, the lack of comprehensive, inclusive programs leaves significant gaps in students' understanding of sexual health. Comprehensive sex education, on the other hand, has proven to be more effective in empowering individuals to make informed, safer decisions regarding their sexual health and well-being.^{6,4}

Sexual well-being is deeply connected to comfort in one's sexuality, sexual activity levels, and relationship satisfaction.² While women who are more comfortable with their sexuality typically report higher sexual well-being, men may experience it differently. Some studies suggest that men associate sexual well-being with frequent sexual thoughts—often referred to as sexual preoccupation—rather than emotional intimacy.¹¹ This difference in perspective highlights the need for sex education programs to address gender-specific attitudes toward sexuality and intimacy. Traditionally, societal beliefs suggest men prioritize physical aspects of relationships over emotional connection. However, newer research indicates that men are placing greater value on emotional intimacy and love before sex, reflecting changing attitudes in younger generations.¹¹

These factors are critical to the quality of relationships, as individuals with greater knowledge and confidence regarding their sexual health and bodies tend to establish more fulfilling partnerships.¹² Perceptions of virginity also vary widely, with some individuals viewing the concept of virginity as a sacred act reserved for marriage, while others see it as a foundational experience for developing love and intimacy.^{12,13} These differing perceptions can influence sexual outcomes and enhance overall sexual satisfaction.^{12,13}

Extensive research directly challenges the misconception that discussing sex encourages harmful sexual behavior, as evidence consistently shows the opposite effect. Comprehensive sex education equips individuals with the knowledge and skills to make informed, safer decisions, reinforcing the importance of well-rounded education in promoting healthy sexual behavior and overall sexual well-being.⁴ Studies have shown that these programs delay the onset of sexual activity, reduce the number of sexual partners, and increase the use of contraceptives. Through comprehensive programs, individuals can develop greater self-awareness, boost self-esteem, confront gender and sexual discrimination, and navigate unwanted sexual encounters more effectively.^{6,4}

This study aimed to explore the impacts of three common sex education approaches—love and intimacy-based, biology-based, and abstinence-based—on individuals' perceptions of sex, virginity, love, intimacy, and sexual well-being. Rather than pitting these approaches against each other, the intention was to highlight the strengths and critical elements of **each**. Relationship-focused sex education, often centered around emotional literacy and relational dynamics, has been shown to foster inclusivity and healthy emotional connections.¹³ In contrast, biology-based programs focus on the physical and reproductive aspects of sex, which can improve informed decision-making about sexual health.² Meanwhile, abstinence-based programs emphasize personal responsibility and often discourage premarital sexual activity, though research suggests they may fail to address emotional or relational complexities.^{6,15} By evaluating the strengths and limitations of each approach, this research aims to provide insights into how these different strategies influence sexual attitudes and behaviors and contribute to the development of a more integrated model for sex education.

The Current Study

This research introduces a paradigm for examining three distinct approaches to sex education: love and intimacy-based, biology-based, and abstinence-based. These approaches represent common methods of sex education used in various curricula, each with a unique focus on different dimensions of sexual well-being. Relationship-focused sex education, often centered around emotional literacy and relational dynamics, has been shown to foster inclusivity and healthy emotional connections.^{14,15} In contrast, biology-based programs emphasize the physical and reproductive aspects of sex, improving informed decision-making regarding sexual health.² Meanwhile, abstinence-based programs highlight personal responsibility and discourage premarital sexual activity, though they often fail to address emotional or relational complexities.^{6,16} However, there remains a gap in the literature regarding how these approaches influence sexual well-being, perceptions of sex, and attitudes toward intimacy.¹⁷ By examining the impacts of these approaches, this study aims to provide insights into developing a more integrated model for sex education that incorporates emotional, relational, and biological components.

This study investigated the respective impacts of these approaches on individuals' sexual well-being, attitudes toward sex, and relationship experiences. Additionally, we examined participants' preferences for specific types of sex education, referred to as *chosen sex education perspectives*, and how gender differences played a role in shaping outcomes. These individual preferences, often shaped by family values, cultural beliefs, or peer influences, and gender-specific views were critical in understanding how participants engaged with and benefited from the educational approaches. The study explored how these factors influenced participants' sexual well-being, including their confidence, comfort with intimacy, and overall relationship satisfaction.

To test these hypotheses, the study employed several statistical analyses. First, we compared the effects of the three different sex education approaches (love and intimacy-based, biology-based, and abstinence-based) on sexual well-being, perceptions of virginity (e.g., gift, stigma, and process), and beliefs about love and intimacy. Educational manipulations were designed to shift participants' perspectives on these topics, which were expected to impact the dependent variables. In addition to examining the direct effects of these manipulations, we analyzed participants' chosen sex education perspectives to determine how personal preferences interacted with the educational approaches. The study also considered how gender differences influenced the outcomes.

A one-way ANOVA was used to evaluate differences between conditions, exploring how each educational approach shaped sexual well-being, attitudes toward virginity, and perceptions of love and intimacy. Further ANOVA tests were conducted to assess differences based on participants' chosen sex education perspectives and gender, particularly focusing on how these factors influenced their engagement with the sex education mediums. Additionally, multiple regression analyses were performed to assess the interactions between gender, chosen sex education perspectives, and the assigned educational condition on participants' perceptions of sexual well-being and virginity.

The study compared the effects of different sex education approaches on sexual well-being and individuals' perceptions of sex and virginity. The educational manipulations (love and intimacy-based, biology-based, and abstinence-based) were designed to influence participants' perspectives on sex education, which were expected to impact the dependent variables—sexual well-being, perceptions of virginity, and attitudes toward sex. The goal was to compare how each educational approach shaped these outcomes. By examining the effects of the manipulations on the dependent variables, the study aimed to provide a more comprehensive understanding of how different sex education strategies impact key dimensions of sexual health.

The primary hypothesis predicted notable differences between the educational conditions (i.e., the manipulated types of sex education approaches: love and intimacy-based, biology-based, and abstinence-based). Love and intimacy-based education was anticipated to yield higher levels of sexual well-being due to its emphasis on inclusivity and acceptance.¹³ Biology-based education was expected to enhance perceptions of sex-related knowledge, while abstinence-based education was predicted to foster positive perceptions of virginity.¹⁸ A secondary hypothesis predicted that participants' chosen sex education perspectives and gender differences would significantly influence the outcomes, potentially shaping their engagement with and perceptions of the educational approaches.

METHODS AND PROCEDURES

Participants

Participants were recruited via Texas A&M University's online research subject pool (SONA). Eligibility criteria required participants to be at least 18 years of age. Informed consent was obtained from all participants prior to their involvement in the study. The final sample comprised 108 men, 64 women, four non-binary individuals, and one participant who self-identified as other.

Demographics

A basic demographics questionnaire was administered to gather detailed information on participants' religious affiliation, sexual experiences, gender, sexual orientation, and political affiliation. Participants had the option to skip any question or select "Don't know" when applicable. Religious affiliation was identified from a predefined list, and religiosity was assessed using a 5-point Likert scale. Sexual experience was measured on a 10-point Likert scale, with participants also indicating their virginity status and reporting the age and context of their virginity loss.¹⁷ Political affiliation was assessed through two 10-point Likert scales: one ranging from "Conservative" to "Liberal," and the other from "Republican" to "Democrat."

Design

Participants were randomly assigned to one of four conditions: love and intimacy-based, biology-based, abstinence-based, or control. Those assigned to the educational conditions watched a nine-minute sex education video tailored to their specific

perspective. In contrast, participants in the control group did not receive any educational material. Following the video (or, for the control group, no video), all participants completed post-intervention questionnaires.

Love and Intimacy Based Sex Education Condition: Script and Language Style

This condition was designed to promote confidence in one's body and sexual experiences by emphasizing the importance of communication and intimacy for fulfilling relationships, both platonic and romantic. The aim was to foster a sex-positive mindset by normalizing sexual experiences and encouraging openness with oneself and one's partner.¹³

Script Excerpt.

"It might be best to see sex, sexual acts, and physical intimacy in general as part of the very human, important, and *precious* process of *communicating and experiencing* love, respect, understanding, and appreciation."

Biology-Based Sex Education Condition: Script and Language Style

This condition provided a comprehensive overview of the reproductive system, utilizing precise medical terminology. It explained processes such as intercourse and masturbation while emphasizing the importance of understanding both male and female bodies.²

Script Excerpt.

"Hormones are the chemical messengers that travel throughout your whole body through your bloodstream. It is absolutely essential to keep this in mind: your hormones influence your body *holistically*."

Abstinence-Based Sex Education Condition: Script and Language Style

This condition maintained a neutral tone, focusing on the biological functions of sex, particularly in reproduction. It emphasized the sacredness of sex and encouraged abstinence, regardless of virginity status. The script discussed the emotional impacts of early sexual activity and highlighted the benefits of abstaining from sex.¹⁶

Script Excerpt.

"Building a family between two loving and prepared adults can be one of life's greatest joys. However, becoming pregnant before you are ready is an outcome that can best be avoided by abstinence."

Control Condition

Participants in the control condition did not receive any scripted sex education material and proceeded directly to the surveys without viewing a video.

Measures and Materials

Sex Education Conditions

Participants in the experimental conditions viewed a nine-minute video tailored to their assigned perspective—love and intimacy-based, biology-based, or abstinence-based. Each video addressed key topics, including safe sex practices and the importance of consent. The videos were developed following an extensive literature review and underwent expert review to ensure they were aligned with the intended educational objectives.¹⁴

Perceptions of Virginity

The *Perceptions of Virginity Scale* is a five-point Likert scale that assesses participants' beliefs about virginity, with subscales categorizing perceptions into "Gift," "Stigma," and "Process."¹⁸ The scale was adapted to reflect participants' self-identified virginity status. Virgins completed the *Perceptions of Virginity Scale (Virgin)*, while non-virgins completed the *Perceptions of Virginity Scale (Non-Virgin)*.

Sexual Well-being

The *Sexual Well-Being Scale* measures participants' satisfaction with their sex life using a 10-point Likert scale.¹³

Perceptions of Love and Sex

The *Love and Intimacy Scale* is a five-point Likert scale that measures the importance of love and intimacy in relationships. Key subscales include "Love is Most Important" and "Sex Demonstrates Love."¹⁹

Sex Ed Perspective & Average Sex Ed Satisfaction

Participants identified their preferred or "chosen" sex education perspective and indicated the type of sex education they had previously received. They also rated their satisfaction with their sex education on a 10-point Likert scale.

Procedure

After completing the demographics questionnaire, participants were randomly assigned to one of four conditions: love and intimacy-based sex education, biology-based sex education, abstinence-based sex education, or the control condition. Participants in the experimental groups watched a nine-minute video tailored to their assigned perspective, with an eight-minute timer lock in place to ensure engagement before they could proceed. The videos were presented as PowerPoint slides with a scripted voice-over narration.

Following the video (or lack of video for the control group), participants completed one of two versions of the post-intervention questionnaires, determined by their response to the question, "Are you currently a virgin?" Control group participants completed the same post-intervention questionnaires as those in the experimental groups, despite not receiving any educational material.

After completing the questionnaires, participants responded to three additional questions regarding their beliefs, the sex education they received, and their satisfaction with that education. Finally, participants were given the option to view the other sex education videos or opt out before receiving debriefing information.

Data Analysis

Data were analyzed using one-way ANOVAs and multiple regression analyses to assess the effects of the different sex education conditions (love and intimacy-based, biology-based, abstinence-based, and control) on participants' perceptions of virginity (*Gift*, *Stigma*, and *Process* subscales), sexual well-being, and beliefs about love and intimacy (e.g., *Love Is Most Important*, *Sex Demonstrates Love*). One-way ANOVAs were used to compare group differences across these outcome measures.

In addition to ANOVAs, multiple regression analyses were conducted to examine how gender and participants' chosen sex education perspective (love and intimacy-based, biology-based, abstinence-based) predicted perceptions of virginity, sexual well-being, and beliefs about love and intimacy. Demographic factors, such as gender and chosen sex education perspective, were entered in step 1 of the regression analysis, while the assigned sex education conditions were added in step 2. This hierarchical method allowed for a comparison of condition effects while controlling for key demographic factors. The significance level was set at $p < 0.05$ for all analyses.

RESULTS

Demographic Characteristics

The demographic characteristics of the participants are summarized in **Table 1**. The majority of participants were men (61%), with women making up 36%, non-binary individuals comprising 2%, and 1% identifying as another gender. Sexual orientation was predominantly heterosexual (82%), followed by asexual (4%), bisexual (6%), gay (2%), lesbian (1%), pansexual (2%), queer (2%), and other (1%).

Religiosity levels among participants varied, with 16% identifying as not religious and 20% reporting that they were very religious. The majority described themselves as slightly religious (27%) or moderately religious (36%). Regarding religious engagement, 28% of participants indicated strong adherence to religious practices, 39% reported moderate adherence, 15% had no religious engagement, and 19% reported minimal engagement.

Political affiliation was measured on a 10-point Likert scale, ranging from conservative to liberal. The majority of participants identified as moderate (56%), with 28% identifying as conservative and 16% as liberal.

Category	Subcategory	Percentage
Gender	Men	61%
	Women	36%
	Non-binary	2%
	Other	1%
Sexual Orientation	Heterosexual/Straight	82%
	Asexual	4%
	Bisexual	6%
	Gay	2%
	Lesbian	1%
	Pansexual	2%
	Queer	2%
	Other	1%
	Other	1%
	Religiosity	Not religious
Slightly religious		27%
Moderately religious		36%
Very religious		20%
Religious Engagement	Yes, strongly	28%
	Yes, somewhat	39%
	No	15%
	Not really	19%
Political Affiliation	1 (Conservative)	-
	2	12%
	3	9%
	4	7%
	5 (Moderate)	56%
	6 (Liberal)	8%
	7	10%
	8	6%
	9	6%
	10	-

Table 1. Demographic Distribution.

Sexual Experience and Virginity Status

Sexual experience and virginity status of participants are summarized in **Table 2**. Sexual experience ratings showed significant variability, with 18% of participants reporting low levels of experience, 18% reporting moderate levels, and 18% reporting high levels of experience.

In terms of virginity status, the majority of participants (55%) were not virgins by any definition, while 35% identified as virgins by all definitions. Among sexually active participants, 75% reported a positive and consensual experience, 17% reported a negative but consensual experience, and 1% reported a negative, non-consensual experience. Most participants reported losing their virginity between the ages of 17-20 (52%) or between the ages of 16-11 (43%).

Category	Subcategory	Percentage
Sexual Experience	1 (Not at all Experienced)	18%
	2	10%
	3	3%
	4	5%
	5	18%
	6	11%
	7	11%
	8	18%
	9	4%
	10 (Very Experienced)	3%
Virginity Status	No, by all definitions	55%
	Yes, by all definitions	35%
	Yes, by my definition	4%
Virginity Loss Experience	No, by my definition	6%
	Positive, consensual	75%
	Negative, consensual	17%
Age of Virginity Loss	Negative, non-consensual	1%
	20-17 years old	52%
	16-11 years old	43%
	Other	-

Table 2. Sexual Experience and Virginity Status.

Sex Education Medium and Satisfaction

Participants were asked to indicate which of five potential sex education mediums they had encountered and rated their satisfaction with each on a 10-point scale, with 10 representing the highest satisfaction. The satisfaction ratings for each medium were averaged, as shown in Table 3. The overall mean satisfaction score across all mediums was 6.42.

Sex-Education Medium	Frequency	Average Satisfaction (1-10)
Peer Education/Word of Mouth	142	6.18
Self-directed (Books, Podcasts, Internet)	115	6.43
One General Health Course in High School	94	6.65
Sexual Education via Parents	74	6.73
A Few Sexual Education Courses in High School	48	6.94

Table 3. Sex Education Medium and Satisfaction Levels.

Analysis of Variance (ANOVAs)

Gender Differences

A one-way ANOVA was conducted to evaluate the impact of gender on key outcome measures, comparing male and female participants. Due to the limited representation of non-binary individuals and others, their data were excluded from this analysis to ensure statistical validity. Significant gender differences were observed for five outcome variables, as shown in Table 5.

Descriptive statistics and ANOVA results are summarized in Tables 4 and 4.1.

	Sum of Squares	df	Mean Square	F	p	η^2
POVGiftAverage	1.13	1	1.13	1.06	0.30	0.006
POVStigmaAverage*	5.86	1	5.86	7.15	0.09	0.040
POVProcessAverage*	3.78	1	3.78	3.99	0.05	0.023
POVtotalAvg	0.48	1	0.48	1.22	0.27	0.007
SexWellBeingSum	37.35	1	37.35	0.37	0.54	0.002
PSL.LoveIsMostImpAverage*	2.43	1	2.43	5.20	0.02	0.030
PSL.SexDemoLoveAverage*	17.99	1	17.99	21.58	<0.001	0.113
PSL.LoveComesB4SexAverage*	7.47	1	7.47	7.96	0.01	0.045
PSL.SexIsDecliningAverage	2.06	1	2.06	2.37	0.13	0.014
PSLtotalAvg	0.05	1	0.05	0.38	0.54	0.002

Table 4. One-Way ANOVA results. Testing differences in outcomes between genders (Male/Female).

Note. The difference is significant at the 0.05 level. The following data was coded with Women = 1 and Men = 2.

	Mean	SD
POVGiftAverage	3.43	1.03
POVStigmaAverage*	1.82	0.92
POVProcessAverage*	3.15	0.98
POVtotalAvg	2.82	0.63
SexWellBeingSum	28.49	9.98
PSL.LoveIsMostImpAverage*	4.09	0.69
PSL.SexDemoLoveAverage*	2.64	0.97
PSL.LoveComesB4SexAverage*	3.85	0.99
PSL.SexIsDecliningAverage	2.37	0.94
PSLtotalAvg	3.34	0.35

Table 4.1. Descriptive statistics for gender differences in outcome measures.

Note. The difference is significant at the 0.05 level

Significant gender effects were observed across several outcome measures. On the *Stigma* subscale of the *Perceptions of Virginity Scale*, women ($M = 2.06, SD = 0.97$) reported significantly higher levels of stigma compared to men ($M = 1.68, SD = 0.86$) [$F(1, 170) = 7.15, p = .008, \eta^2 = 0.015$]. A similar gender effect was found on the *Process* subscale, where women ($M = 3.34, SD = 0.91$) reported higher levels than men ($M = 3.04, SD = 1.01$) [$F(1, 170) = 3.99, p = .05, \eta^2 = 0.021$].

Further, significant gender effects were found on the *Love Is Most Important* subscale of the *Perceptions of Love and Sex Scale*, with men ($M = 4.18, SD = 0.65$) placing more importance on love compared to women ($M = 3.93, SD = 0.74$) [$F(1, 170) = 5.20, p = .024, \eta^2 = 0.007$]. Women ($M = 3.06, SD = 0.87$) reported significantly higher levels of *Sex Demonstrates Love* compared to men ($M = 2.39, SD = 0.94$) [$F(1, 170) = 21.58, p < .001, \eta^2 = 0.008$]. Finally, men ($M = 4.01, SD = 0.95$) were more likely to believe *Love Comes Before Sex* compared to women ($M = 3.58, SD = 1.00$) [$F(1, 170) = 7.96, p = .005, \eta^2 = 0.042$].

Additionally, significant gender effects were observed on the *Love Is Most Important* subscale of the *Perceptions of Love and Sex Scale*, with men ($M = 4.18, SD = 0.65$) placing more importance on love than women ($M = 3.93, SD = 0.74$) [$F(1, 170) = 5.20, p = .024, \eta^2 = 0.007$]. Women ($M = 3.06, SD = 0.87$) reported significantly higher levels on the *Sex Demonstrates Love* subscale compared to men ($M = 2.39, SD = 0.94$) [$F(1, 170) = 21.58, p < .001, \eta^2 = 0.008$]. Finally, men ($M = 4.01, SD = 0.95$) were more likely to believe that *Love Comes Before Sex* than women ($M = 3.58, SD = 1.00$) [$F(1, 170) = 7.96, p = .005, \eta^2 = 0.042$].

Condition Differences

A one-way ANOVA was conducted to evaluate the differences between the four conditions (love and intimacy-based, biology-based, abstinence-based, and control) on key outcome measures, including perceptions of virginity (Gift, Stigma, and Process subscales), sexual well-being, and beliefs about love and intimacy (e.g., Love Is Most Important, Sex Demonstrates Love). The analysis revealed no significant effects of the sex education conditions on these outcomes, as summarized in **Table 5**. Descriptive statistics for each outcome are detailed in **Table 5.1**.

	Sum of Squares	df	Mean Square	F	p	η ²
POVGiftAverage	2.70	3	0.90	0.85	0.47	0.014
POVStigmaAverage	2.22	3	0.74	0.87	0.46	0.015
POVProcessAverage	3.59	3	1.20	1.24	0.30	0.021
POVtotalAvg	0.67	3	0.22	0.56	0.64	0.010
SexWellBeingSum	191.43	3	63.81	0.64	0.59	0.011
PSL.LoveIsMostImpAverage	0.62	3	0.21	0.42	0.74	0.007
PSL.SexDemoLoveAverage	1.28	3	0.43	0.45	0.72	0.008
PSL.LoveComesB4SexAverage	7.27	3	2.42	2.52	0.06	0.042
PSL.SexIsDecliningAverage	4.30	3	1.43	1.64	0.18	0.028
PSLtotalAvg	0.04	3	0.01	0.10	0.96	0.002

Table 5. One-Way ANOVA results. Testing differences in outcomes between conditions.

Note. The difference is significant at the 0.05 level. The data was coded as follows: Love and intimacy-based condition = 1, Biology-based condition = 2, Abstinence-based condition = 3, and Control condition = 4. Abbreviations: *POVGiftAverage*: Perceptions of Virginity – Gift subscale average; *POVStigmaAverage*: Perceptions of Virginity – Stigma subscale average; *POVProcessAverage*: Perceptions of Virginity – Process subscale average; *POVtotalAvg*: Total Perceptions of Virginity average; *SexWellBeingSum*: Total score for Sexual Well-Being; *PSL.SexDemoLoveAverage*: Perceptions of Love and Sex – Sex Demonstrates Love subscale average; *PSL.LoveComesB4SexAverage*: Perceptions of Love and Sex – Love Comes Before Sex subscale average; *PSL.SexIsDecliningAverage*: Perceptions of Love and Sex – Sex Is Declining subscale average; *PSLtotalAvg*: Total Perceptions of Love and Sex average.

	Mean	SD
POVGiftAverage	3.42	1.03
POVStigmaAverage	1.82	0.92
POVProcessAverage	3.16	0.98
POVtotalAvg	2.82	0.63
SexWellBeingSum	28.59	9.95
PSL.LoveIsMostImpAverage	4.09	0.70
PSL.SexDemoLoveAverage	2.66	0.98
PSL.LoveComesB4SexAverage	3.84	0.99
PSL.SexIsDecliningAverage	2.34	0.94
PSLtotalAvg	3.34	0.37

Table 5.1. Descriptive statistics for outcomes across conditions.

Note. The difference is significant at the 0.05 level

Chosen Sex Education Perspective

A one-way ANOVA was conducted to examine differences in participants' chosen sex education perspectives. Two significant effects were observed, shown in Table 6, with descriptive statistics in Table 6.1.

	Sum of Squares	df	Mean Square	F	p	η ²
POVGiftAverage*	10.02	2	5.01	4.93	0.01	0.05
POVStigmaAverage	0.85	2	0.43	0.50	0.61	0.01
POVProcessAverage	3.95	2	1.97	2.10	0.13	0.02
POVtotalAvg	0.91	2	0.45	1.16	0.32	0.01
SexWellBeingSum	117.03	2	58.51	0.59	0.57	0.07
PSL.LoveIsMostImpAverage	1.26	2	0.63	1.28	0.28	0.02
PSL.SexDemoLoveAverage	1.96	2	0.98	1.03	0.36	0.01
PSL.LoveComesB4SexAverage*	12.64	2	6.32	6.82	0.001	0.07
PSL.SexIsDecliningAverage	1.65	2	0.82	0.93	0.40	0.01
PSLtotalAvg	0.57	2	0.28	2.11	0.12	0.02

Table 6. One-Way ANOVA results. Testing differences in outcomes between chosen sex education perspectives.

Note. The difference is significant at the 0.05 level. The following data was coded with the Love and intimacy-based condition = 1, Biology-based condition = 2, and Abstinence-based condition = 3

	Mean	SD
POVGiftAverage*	3.42	1.03
POVStigmaAverage	1.82	0.92
POVProcessAverage	3.16	0.98
POVtotalAvg	2.82	0.63
SexWellBeingSum	28.59	9.95
PSL.LoveIsMostImpAverage	4.09	0.70
PSL.SexDemoLoveAverage	2.66	0.98
PSL.LoveComesB4SexAverage*	3.8	0.99
PSL.SexIsDecliningAverage	2.34	0.94
PSL.totalAvg	3.34	0.37

Table 6.1. Descriptive statistics for chosen sex education perspectives in outcome measures.
Note. The difference is significant at the 0.05 level

A significant effect of the chosen sex education perspective was observed on the *Gift* subscale of the *Perceptions of Virginit Scale* [$F(2, 174) = 4.93, p = .008, \eta^2 = 0.006$]. Post hoc comparisons using the Tukey HSD test revealed a significant difference between the abstinence group ($M = 3.84, SD = 1.08$) and the biology group ($M = 2.97, SD = 1.09$), but no significant difference between the love and intimacy groups ($M = 3.40, SD = 0.97$) and the abstinence or biology groups.

Similarly, a significant effect was found on the *Love Comes Before Sex* subscale [$F(2, 174) = 6.82, p = .001, \eta^2 = 0.045$]. Post hoc analysis revealed a significant difference between the biology group ($M = 3.36, SD = 1.05$) and the abstinence group ($M = 4.32, SD = 0.82$), but no significant difference between the love and intimacy groups ($M = 3.81, SD = 0.98$) and the biology or abstinence groups.

Multiple Regression Analysis

Multiple regression analyses were performed to examine the influence of gender and chosen sex education perspectives (love and intimacy-based, biology-based, abstinence-based) on participants' perceptions of virginit, sexual well-being, and beliefs about love and intimacy. Significant demographic variables (gender and chosen sex education perspective), as identified in the ANOVAs, were entered in step 1 of each regression analysis, while the assigned sex education conditions were added in step 2. A summary of the regression analysis results is provided in **Table 7**.

	Predictors	R	R ²	Adjusted R ²	F	p
POVStigmaAverage	Gender	0.20	0.04	0.04	7.15	0.01
POVProcessAverage	ChosenAbstinence, Gender, ConLove	0.27	0.07	0.06	4.35	0.01
PSL.LoveIsMostImpAverage	Gender	0.17	0.03	0.02	5.20	0.02
PSL.SexDemoLoveAverage	Gender	0.34	0.11	0.11	21.58	<.001
PSL.LoveComesB4SexAverage	ChosenAbstinence, Gender, ConControl, Bio	0.43	0.18	0.16	9.22	<.001

Table 7. Multiple Regression Analysis Summary.

Note. The difference is significant at the 0.05 level. Abbreviations: *POVStigmaAverage*: Perceptions of Virginit – Stigma subscale average; *POVProcessAverage*: Perceptions of Virginit – Process subscale average; *PSL.LoveIsMostImpAverage*: Perceptions of Love and Sex – Love Is Most Important subscale average; *PSL.SexDemoLoveAverage*: Perceptions of Love and Sex – Sex Demonstrates Love subscale average; *PSL.LoveComesB4SexAverage2*: Perceptions of Love and Sex – Love Comes Before Sex subscale average.

The regression analyses indicated that gender was a significant predictor for *POVStigmaAverage*, accounting for 4% of the variance, with women reporting higher levels of stigma than men ($\beta = -.201, p = .008$). For *POVProcessAverage*, chosen abstinence perspective, gender, and the love-based condition together accounted for 7.2% of the variance, with participants in the chosen abstinence group and women reporting higher levels of process perception ($\beta = -.172, p = .022; \beta = -.162, p = .032$).

In the case of *PSL.LoveIsMostImpAverage*, gender was a significant predictor, accounting for 3% of the variance, with men placing more importance on love than women ($\beta = .172, p = .024$). For *PSL.SexDemoLoveAverage*, gender was again a significant predictor, accounting for 11.3% of the variance, with women reporting higher levels of *Sex Demonstrates Love* than men ($\beta = -.336, p < .001$). Finally, for *PSL.LoveComesB4SexAverage*, chosen abstinence perspective, gender, control, and biology conditions together accounted for 18.1% of the variance, with participants in the chosen abstinence group and men reporting higher levels of *Love Comes Before Sex* ($\beta = .253, p < .001; \beta = .198, p = .006$).

These findings underscore that both gender and preexisting perspectives significantly shape participants' views on virginity and sexual well-being. The data highlight the importance of considering these factors when designing sex education programs.

DISCUSSION

Contrary to our hypotheses, the one-way analysis of variance (ANOVA) revealed no significant differences between the four assigned sex education conditions. We initially hypothesized that the love and intimacy-based condition would enhance sexual well-being, the biology-based condition would improve sex-related knowledge, and the abstinence-based condition would reinforce positive perceptions of virginity. However, these hypotheses were not supported by the findings. The results do not indicate significant differences between the experimental conditions. However, further analysis suggests that participants' preexisting perspectives may have influenced their responses, which potentially overshadowed the effects of the experimental conditions.^{11,16} The brief nine-minute sex education videos may have been insufficient to alter participants' deeply ingrained beliefs. This implies that more comprehensive and sustained programs are necessary to create meaningful changes in attitudes toward sex and virginity.^{2,16}

Gender Considerations and Study Limitations

Gender analyses were conducted exclusively on data from participants who identified as female or male, excluding non-binary or other gender identities. The predominance of heterosexual males in the sample may have introduced response biases. Significant gender differences were observed for five outcome measures: *Stigma* and *Process* from the *Perceptions of Virginity Scale*, and *Love Is Most Important*, *Sex Demonstrates Love*, and *Love Comes Before Sex* from the *Perceptions of Love & Sex Scale*. These results suggest that women experience greater stigma around virginity and view sex as a milestone, while men place greater importance on love before sex.²⁰

Given the heteronormative nature of the sample, future research should explicitly recruit non-binary and LGBTQ participants to ensure inclusivity. Studies should also explore potential discomfort participants may experience when engaging with sexual content, as well as investigating diverse perspectives on sex and sexuality. Previous research has documented similar challenges in navigating sensitive topics like sex education.²¹ Although this study makes a modest contribution, it moves the discourse forward on sex-related topics and highlights the need for more inclusive sex education research.

The significant effects observed in participants' chosen sex education perspectives underscore the impact of preexisting views. For example, significant results were found on the *Gift* subscale from the *Perceptions of Virginity Scale* and the *Love Comes Before Sex* subscale from the *Perceptions of Love & Sex Scale*. These findings suggest that participants with an abstinence-focused perspective view virginity as a cherished gift and prioritize love before sex.^{17,18} This reinforces the idea that preexisting beliefs and attitudes are highly influential and can overshadow the effects of brief educational interventions. Effective sex education programs should engage with these preexisting beliefs, presenting information that encourages critical reflection, while acknowledging that certain beliefs may remain strong. One possible interpretation of this finding is that the reinforcement of preexisting perspectives—such as those around abstinence—could explain the limited influence of the educational interventions.⁶ Other factors, such as cultural or familial values, might also contribute to this outcome.¹⁷ While many individuals may have already been exposed to some form of sex education, the quality and scope of that education can vary significantly. Without access to a more comprehensive and balanced curriculum, individuals might continue to rely on incomplete or biased information from peers or media, reinforcing their existing beliefs.¹³ Comprehensive sex education is essential in helping individuals develop a well-rounded understanding of sexual health and challenge any misconceptions they may hold.²²

The study's report on participants' satisfaction with prior sex education provides additional context. Participants expressed the highest satisfaction when they received at least some of their sex education through structured high school courses, although this was the least common source. Similarly, receiving sex education from parents, while also less common, resulted in the second-highest satisfaction levels. Conversely, participants who received sex education from peers or word of mouth reported the lowest satisfaction levels. Despite these differences, satisfaction scores across all sources fell within a relatively narrow range, and the overall average score of 6.5/10 indicates there is significant room for improvement across all sex education mediums.³

Implications for Sex Education Programs

These findings highlight an important insight: informal sources of sex education, while easily accessible, often lack the comprehensive, reliable information provided by formal education.¹⁰ This disparity emphasizes the need for structured, well-rounded sex education programs designed to equip individuals with accurate and diverse perspectives on sexuality. Effective sex education should go beyond the dissemination of information—it should provide sustained, step-by-step education on practical skills like condom use and contraception, similar to how academic subjects are taught over several lessons.⁴ Just as students are taught how to solve math problems through repetition and practice, sexual health education should engage participants in active learning over time to ensure they understand not just the facts but also how to apply them in real-life contexts.⁵ This supports the

argument for integrating comprehensive sex education into school curricula to ensure individuals receive the tools and knowledge necessary to navigate their sexual lives confidently.

Integrating Different Educational Approaches

The study's findings represent a preliminary step in the development of sex education programs by integrating insights from each approach. Love and intimacy-based education amplifies the beauty of sex and its inevitability, but it might leave individuals vulnerable to emotional challenges if trust is not emphasized. The biological approach provides valuable information on the mechanics of sex and reproductive processes but can overlook emotional and psychological aspects crucial to healthy sexual relationships.² Abstinence-based education highlights the sacredness of sex and the consequences of premature sexual activity but risks stigmatizing a natural human behavior.⁶ Each approach has its strengths, but they are most effective when integrated into a comprehensive program that addresses the multifaceted nature of human sexuality.

Implications for Gender and Preexisting Perspectives

The regression analyses further illustrate the influence of gender and preexisting sex education perspectives on participants' perceptions of virginity, sexual well-being, and attitudes toward love and intimacy. Notably, gender differences were evident in key outcomes, such as *Stigma* and *Process* from the *Perceptions of Virginity Scale* and *Love Is Most Important* from the *Perceptions of Love & Sex Scale*. These findings suggest that women may experience greater stigma surrounding virginity and view sex as a rite of passage, while men may place higher value on emotional intimacy, prioritizing love before sex.

Interestingly, men placing higher importance on love before sex contrasts with traditional gender norms, which often portray men as prioritizing the physical aspects of relationships over emotional connections. As research has shown, shifting cultural norms and educational influences may explain this change in attitudes among younger generations.¹⁴ This suggests that cultural and educational factors emphasizing emotional intimacy may have influenced these attitudes. The complexity of evolving gender roles and their impact on sexual experiences highlights the need for sex education programs that address and integrate these nuanced perspectives to meet the diverse needs of individuals.

The limited impact of the assigned conditions in the study—particularly the nine-minute educational interventions—suggests that short-term efforts are insufficient to meaningfully influence deeply held beliefs about sex and relationships. This underscores the importance of long-term, comprehensive sex education programs that engage participants over time and provide opportunities for reflection and growth. While brief educational efforts may be useful as part of a broader curriculum, they cannot replace the depth and consistency required to shift ingrained perspectives.

Reluctance to Discuss Sex-Related Issues

Participants' reluctance to openly discuss sex-related issues can reinforce preconceived notions and hinder meaningful changes in their perspectives. This limitation should be considered when interpreting the results, as discomfort in addressing sensitive topics might have influenced participants' engagement with the material.¹ Real education on sexual health must grapple with these difficult, often taboo subjects, making them unavoidable in comprehensive programs.²³ While the study's online format allowed for greater anonymity, it cannot fully eliminate the cultural or personal barriers that lead to hesitation in expressing views about sensitive topics. Ethical considerations in sex education research must acknowledge this discomfort while aiming to create educational environments that promote openness and dialogue around complex and taboo subjects.²¹ In practice, addressing sensitive issues in sex education may require extended time and trust-building to overcome reluctance and foster an atmosphere conducive to open discussion.

Challenges of Societal Shifts in Sex Education

Addressing societal reluctance to openly discuss sex-related topics represents a broader challenge that extends beyond individual participants. A societal shift toward more open discussions about sexuality is necessary to improve the effectiveness of sex education.²¹ However, this raises ethical considerations, as educators and policymakers must navigate the fine line between respecting cultural values and pushing for progressive, inclusive dialogues about sexual well-being, relationships, and consent.⁹ This balance can be difficult, as the sensitivity of these topics often creates resistance or discomfort. Breaking down societal taboos and encouraging comprehensive dialogue around these issues is essential, but must be handled with care to avoid alienating individuals or communities. Although this study contributes to the empirical literature on sex education, it also highlights the ongoing need for evidence-based approaches to overcome societal and ethical barriers, fostering environments where these complex topics can be addressed openly.

CONCLUSION

This study provides valuable insights into the complex interplay between gender, chosen sex education perspectives, and the effectiveness of brief educational interventions. The findings emphasize the importance of considering preexisting beliefs and

demographic factors in the design and implementation of sex education programs. Contrary to our hypotheses, the brief nine-minute educational interventions did not result in significant shifts in participants' perspectives. This highlights the need for longer-term, more comprehensive educational programs that offer individuals meaningful opportunities to engage with new information. Future research should focus on developing these more extensive interventions while also recruiting more diverse samples, including non-binary and LGBTQ participants, to ensure inclusivity.

Although the study's contribution is modest, it advances the conversation on sex education by addressing gaps in previous research, particularly by incorporating gender and diverse sex education perspectives. Rather than seeking to determine the "best" approach, this research advocates for an integrated model that combines elements from love and intimacy-based, biology-based, and abstinence-based programs. By exploring these approaches, the study encourages a more holistic view of sex education that includes emotional, psychological, and ethical dimensions—critical factors in fostering well-rounded sexual well-being. Encouraging open discourse on sexual health is essential for understanding the profound impact sex education can have on individuals' self-perception, sexual behaviors, and overall quality of life.

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PRESS SUMMARY

Sex education is crucial for fostering informed and healthy sexual behaviors. This study evaluated three distinct sex education approaches—love and intimacy-based, biology-based, and abstinence-based—against a control group. While no statistically significant differences emerged among the four conditions, significant effects related to participants' chosen sex perspectives and gender differences were observed. These findings provoke thought-provoking questions that align with the study's original aim of advancing sex-related conversations and improving sex education. By highlighting the influence of preexisting beliefs and the role of gender, the research underscores the importance of considering both perceptions and realities in developing comprehensive and inclusive sex education programs.

Identifying SES Factors in the National Household Education Surveys

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ABSTRACT

The purpose of this study was to determine if conceptually and psychometrically rigorous measures of socioeconomic status could be developed for the National Household Educational Surveys (NHES). Exploratory factor analyses were performed for the following NHES: (1) Parent and Family Involvement in Education; (2) School Readiness; (3) Early Childhood Program Participation; (4) After School Programs and Activities; and (5) Adult Education/Adult Education and Lifelong Learning over several years of this administration, including two of the NHES surveys conducted in 2019. The results, while preliminary, suggest that rigorous measures of socioeconomic status (SES) can be constructed for most of the surveys based on Hauser and Warren's model which used income, education, and occupation. This should enhance inferences based on these data and simultaneously increase the appeal of this database to the educational research community. If the measurement of SES is enhanced, it will fundamentally raise the level of quality of research findings and make them more attractive to educational researchers who use the NHES survey database.

KEYWORDS

Educational Attainment; Exploratory Factor Analysis; National Surveys; Parent Involvement; School Readiness; Socioeconomic Status; Data Analysis Methods; Educational Research Databases

INTRODUCTION

The NHES surveys constitute a comprehensive database that provides data on the educational activities of the US population from early childhood through adulthood and, as such, provide fertile ground for the exploration of SES, which has had a model proposed by Hauser and Warren.¹ The NHES comprises five different biannual surveys carried out with households at different periods.² A key NHES survey dataset feature is the need to consider SES to avoid compromising inferences that may occur due to the widely documented impact of SES on a range of educational outcomes.^{3,4} This requires effectively engaging conceptually and psychometrically rigorous measures of SES, which was the ultimate purpose of this study. The present study aims to improve SES measures and, thereby, enhance the strength and validity of inferences based on the NHES surveys while making the NHES survey database more useful and appealing to a much larger audience within the general educational research community.

The availability of such measures should enhance inferences based on these data and increase the appeal of this database to researchers more broadly. Hauser and Warren provided a model arguing that SES is a multidimensional construct composed of householder occupation, education, and income.^{Error! Bookmark not defined.} This conceptualization produces a hierarchy implying that an NHES survey respondent whose SES is "high" has a higher level of education, occupational status, and/or income than a respondent whose SES is "low." We adopt this conceptualization here.

The NHES surveys are one of several databases managed by the National Center for Education Statistics (NCES); others include the National Assessment of Educational Progress (NAEP), High School and Beyond (HSB), the Early Longitudinal Childhood Study (ELCS-K), Current Population Survey (CPS), and the Educational Longitudinal Study of 2002 (ELS). Among the surveys contained in the NCES, raw data are typically available for public download, as they were for the present study. NHES surveys were initially administered in the early 1990s and have since been conducted biannually. Five surveys comprise the NHES: (1) Parent and Family Involvement in Education (PFI); (2) School Readiness (SR); (3) Early Childhood Program Participation (ECP); (4) After School Programs and Activities (ASPA) for Middle School and High School Students; and (5) Adult Education/Adult Education and Lifelong Learning (AE/AELL). Data are collected via phone interviews using a list-assisted sampling method. Not every survey is administered in each NHES survey data collection and only data for 2005 and 2007 are available online. Most data collected are dichotomous yes/no responses; however, responses also include continuous, fill-in-the-blank, and Likert items. A key feature of NHES surveys is that data are collected at the household level.

Although precise usage statistics for NCES databases are not readily available, evidence suggests that NHES surveys are among of the least frequently used by educational researchers. For example, no study published between 2000-2010 in three prominent educational research journals (*American Educational Research Journal*; *Educational Evaluation & Policy Analysis*; *Sociology of Education*) reported using the NHES survey database, whereas several studies used other NCES databases (e.g., ELCS-K, ELS). An aim of this study is to make the NHES survey datasets more appealing to educational researchers through the present analyses and practical explorations of the benefits of using these datasets.

While NHES surveys do not appear to be widely used in the field of educational research, some educational researchers have reported results based on these surveys. For example, Silva *et al.*⁴ studied barriers to adult participation in education, and Zill *et al.*⁵ examined the adjustment of children who enter kindergarten late or repeat kindergarten. One characteristic shared by many analyses of widely used NCES datasets, including NHES, is the need to consider SES in the analyses because a failure to do so can seriously compromise inferences. This occurs because of the widely documented impact of SES on a range of educational outcomes.^{3,4,6}

To successfully control for the effects of SES, there must be one or more conceptually and psychometrically rigorous measures of the concept. These measures can then serve as a control variable in data analyses; for instance, they may act as covariates, matching variables and/or they may figure in propensity models. However, constructing a rigorous measure of SES is challenging due to a potential mismatch between the conceptualization of SES and available variables in a database, significant measurement error associated with variables sometimes used as measures of SES (e.g., eligibility for a free/reduced price lunch), and the presence of missing data.⁷ These problems increase the likelihood that inferences pertaining to outcomes of interest (e.g., householder satisfaction with their child's school) will be biased by a failure to adequately take SES into account.

Purpose of the Study

The NHES survey database offers much to educational researchers because of its detailed focus on pre-primary education, childcare utilization, school safety and discipline, and adult education, especially if one or more rigorous measures of SES are available. However, no previous research has constructed measures of SES for the NHES survey database. The purpose of this study was to determine if conceptually and psychometrically rigorous measures of SES for the NHES survey database can be constructed. Ultimately, it could be a great contribution to future studies and to the utility that the NHES survey database can make in educational research if rigorous measures of SES were available at this level. Though this study may be regarded as an "exploratory study", the availability of such measures should enhance inferences from these data and simultaneously increase the appeal of this database to the educational research community.

LITERATURE REVIEW

Socioeconomic Status

Defining and operationalizing SES is an ongoing process in the scholarly activity of several disciplines including education, psychology and public health, among others. Research shows that living in a high-SES area influences people's daily health choices.⁸ In fact, greater SES has been demonstrated to be protective against increasing HbA1c (Glycated hemoglobin), with physical activity partially mediating this relationship.⁹ SES has also been linked to mental health, with Reiss *et al.*¹⁰ finding that children are at a higher risk for mental health problems when their parents have a lower level of education and subsequently more stressful lives.

However, exploring SES has been complicated by differences in how it is defined and measured across fields. For example, in sociology the terms "social class," "social stratification," or "social mobility" are generally used interchangeably and are associated with a particular theory¹¹ that treats this construct as a latent variable. On the other hand, in education and psychology, the term most used is SES, which is defined by the variables used to measure it in a study rather than a theory of SES, and thus is atheoretical.¹² Educational literature utilizes SES through different definitions such as Hauser and Warren's.¹³ Some literature focusing on education while associating it with SES defined the term in relation to the number of books a parent or guardian has in their home or in relation to their geographical location.¹³ Tan *et al.*¹⁴ provided information on the examination of parent involvement in their children's education regardless of the parent's SES and defines it as the educational level the parent achieved. Bollen *et al.*¹⁵ convincingly argues the feasibility and need for grounding a definition of SES [and class] within research. In order to provide the grounding Bollen is referring to, research, including measures of SES, require consistency in how SES is conceptualized. The NHES surveys provide multiple data that research could consider of interest when examining SES from different fields of study. A few of the datasets within the NHES surveys include those which investigate parental involvement in a child's life and educational success in areas such as cognition, language, and social development (Oswald, 2018).¹⁶ For the purpose of this study, an education-based definition of was utilized.

An examination of SES measures used in educational research reveals few that demonstrate a clear conceptual or psychometric foundation. Moreover, these measures are generally dated (e.g., Hollinghead's index, Siegel Prestige Scale;¹⁷ Duncan Socioeconomic Index) and do not conceptualize SES as a latent variable. Educational research typically views SES as unidimensional, in contrast to Hauser and Warren who view SES as multidimensional^{Error! Bookmark not defined.}, Hauser and Warren suggest SES is a latent variable composed of the three facets of householder occupation, education, and income.¹ The resulting multidimensional conceptualization of SES represents shorthand expression for variables that enable the placement of persons, families, households and aggregates such as statistical local areas, communities and cities in some hierarchical order, reflecting their ability to produce and consume the scarce and valued resources of society.^{Error! Bookmark not defined.} Hauser and Warren's^{Error! Bookmark not defined.} conceptualization implies that a householder (NHES survey respondent) whose SES is "high" has more education, higher occupational status, and/or income than a respondent whose SES is "low", thus suggesting a "hierarchical order" with high SES ranked at the top.

SES has been discussed extensively in terms of its importance to educational outcomes. For example, Tan *et al.*¹⁴ examined the patterns associated with parental involvement variables and the achievement level of students from K-12. Another study by Yerdelen-Damar and Peşman¹⁸ explores SES in relation to students' physics achievement where high school students were observed in the hope of finding a correlation between the different genders and their SES to their achievements in learning and understanding physics. Students benefit from both metacognitive strategies and self-efficacy, but self-efficacy plays a key role in translating metacognitive skills into actual achievement. The study revealed that a parent's SES is connected to a range of different learning strategies used by students, and the results convey a link between the learning methods, meta-cognition and physics self-efficacy, and differences in SES and the different physics achievements. SES had a small but positive relation to students who use different strategies to achieve their goals, in this case learning and succeeding at physics.

Exploratory Factor Analysis

Origins and Purpose

The central goal of factor analysis is to represent a set of observed variables with a set of factors (potentially latent variables) through inter-correlations to generate factors.¹⁹ In the social sciences, factor analysis is generally used for one of three purposes. One is as a purely empirical data reduction technique, usually involving factor analyzing data for the purpose of identifying P factors underlying T observed variables. An example of this use (typically labeled exploratory factor analysis or EFA) can be seen in the work of Bilder *et al.*,²⁰ who analyzed items reflecting positive and negative symptoms of schizophrenia to produce three factors.

A second, and related, purpose is captured by Gorsuch,¹⁹ who defined factor analysis as a form of summary of connected relationships between variables in a manner that is both accurate and concise and that is helpful in developing a conceptualization. Here, interest centers on factors explaining information in the observed variables in ways that are linked to a study's purpose (e.g., identifying subsets of items on a questionnaire reflecting conceptually meaningful subscales). Typically, this is accomplished through EFA. Lyden *et al.*²¹ provide an example of this with their focus on the structure of a modified version of The National Institutes of Health Stroke Scale to compare this scale to an original version.

Some researchers have raised concerns over these two purposes and the use of EFA, most of which center on the potential subjectivity in the process of identifying factors. However, Henson and Roberts²² argued that this process inherently requires a researcher to make informed decisions, and, when done carefully, represents an important and appropriate use of EFA. The research question and methodology which includes defining and operationalizing SES is presented below. The development of an SES measure involves aggregating variables (items) in the NHES survey dataset, which implies the use of factor analytic methods. Specifically, exploratory factor analytic methods were carried out on the surveys analyzed for this research using principal factor analysis (PFA) to examine factors that emerged and whether they can be used as proxy measures for SES, as described below. In the present study, given the treatment of SES as a latent variable (construct/factor), principal factor analysis (PFA) was used, as it extracts common variance, an important element when examining underlying extracted factors.

Extraction Method

Multiple options exist for extracting factors including unweighted least squares, generalized least squares, maximum likelihood, PAF, alpha factoring, and image factoring.²³ According to Fabrigar *et al.*,²⁴ maximum likelihood is optimal because "it allows for the computation of a wide range of indexes of the goodness of fit of the model [and] permits statistical significance testing of factor loadings and correlations among factors and the computation of confidence intervals." Maximum likelihood provides loadings that are most likely and permits hypothesis testing for the loadings. Additionally, the use of maximum likelihood was advantageous given that there are many fit indices available when making use of this extraction method, making it more broadly used. However, Fabrigar *et al.*²⁴ caution that if the assumption of normality is violated, then other methods are recommended. This study used maximum likelihood as the extraction method for each NHES survey (see Mueller⁶ for details of this method).

Number of Factors to Extract

A critical step in EFA is determining the number of factors to extract. This is typically done through methods such as identifying eigenvalues greater than one, the scree test, and Velicer and Jackson's MAP criteria and parallel analysis.²⁵ Costello and Osborne²³ suggest that the scree test is generally the most effective method and involves examining a scree plot and identifying the break where the curve flattens out; data points above the break are considered an adequate number of factors to retain.¹⁹ Examining the scree plot produced for each of the surveys in preliminary analyses helped to determine how many factors to extract and led us to set the number of extracted factors per survey at three (see below). Given this work is exploratory in nature and that a threshold of .30 for factor loadings is commonly used to determine the practical significance of an item in defining a factor,^{26,27,28} it was specified in this study that a variable loading on a factor (i.e., correlation between an item and a factor) had to exceed .30 to treat that variable as helping to define the factor.²⁹

Rotation Method

Extracted factors are sometimes rotated to improve factor structure with respect to interpretation and simplifying and clarifying the data structure. Rotation can be oblique, in which the resulting factors are correlated, and orthogonal, in which the resulting factor loadings are interpreted as simple correlations of items with factors.³⁰ Varimax rotation is considered the most popular method for orthogonal rotation and was used in the factor analyses carried out in this study.

Sample Size

Clear guidance on ideal sample size for factor analysis is arguably not available. Costello and Osborne²³ found that a respondent-to-variable ratio of 10:1 is commonly utilized largely without formal justification. Fortunately, sample size is not an issue in the current study as each of the five surveys used for this study involved at least 2,633 respondents and a ratio of respondents to items exceeding 50:1. Secondary data analyses using factor analyses were carried out on five surveys of the NHES. IRB approval was granted for this study at each participating institution and the data are available to the public and not individually identifiable. Conceptually and empirically distinct SES measures are needed for each survey. The surveys were analyzed to determine if SES measures could be constructed for each NHES survey using Hauser and Warren's³¹ definition. Using the NHES survey database, we sought to determine what factors emerge that can act as a proxy measure for SES.

Research Question

The present study was guided by the following research question:

RQ: Can conceptually and psychometrically rigorous measures of SES be constructed for the NHES survey database using variables and data available within this database? If so, what is the nature of the evidence supporting their construction?

METHOD AND PROCEDURES

Design of the Study

As noted, the NHES surveys consist of five surveys (PFI, SR, ECPP, ASPA, AE/AELL) with a focus on different groups (e.g., elementary age children, high school students). These surveys are conceptually and empirically distinct, and separate SES measures are needed for each. A four-step procedure was used to determine if measures of SES could be constructed for each NHES survey. In all cases, Hauser and Warren's³¹ definition guided the construction of the measures using the variables available in each survey. First, the purpose of each survey was determined using NCES materials to ascertain what types of household information was gathered. Second, pertinent variables in each survey were identified. Third, EFA was conducted to identify potential SES factors. Fourth, construct validity evidence was generated by examining Hauser and Warren's³¹ definition and the resulting factors, and correlations between the factors and variables were identified and explored. This procedure was followed for each of the five surveys in the NHES survey database.

Respondents

The PFI survey of 2007 was completed with the parents of 10,681 children in kindergarten through 12th grade, including 10,370 students enrolled in public or private schools and 311 home-schooled children. The PFI for 2019 was carried out with 14,075 participants. The SR survey data for 2007 were provided by 2,633 children aged 3-6 and kindergarten through second grade. The ECPP survey of 2007 used interviews with 7,209 parents of children aged three through third grade, children from birth through age six, and those not yet in kindergarten. The ECPP survey for 2019 utilized survey data from 7,092 participants. The ASPA of 2005 sample of 11,684 is nationally representative of non-institutionalized students enrolled in kindergarten through eighth grade with a maximum age of 15 years. The AE/AELL survey produced a national sample that provides information on civilian and non-institutionalized persons aged 16 or older and not enrolled in grade 12 or below. Sample sizes for the AE/AELL surveys ranged from 6,697-19,722 non-institutionalized adults aged 16 and older, not enrolled in 12th grade or below, and not on active duty in the US armed forces. The 2005 AE survey was based on 8,904 adults.

Procedures

The four-step procedure for carrying out analyses is detailed below for the 2005 AE survey, with the same steps repeated for the remaining surveys in the current study. The 2005 AE survey collected information on householder participation in college and university programs taken for work-related reasons, postsecondary vocational/technical diploma reasons, apprenticeships, work-related courses, and work-related informal learning (e.g., courses taken to obtain a GED or obtain ESL skills). Only data for the most recently administered surveys that are available online were analyzed.

In step one, the purpose of the AE as outlined in NCES documentation was examined. In general, the AE attempts to characterize adult involvement and attainment in both formal and informal learning activities. Formal activities include those courses where an instructor is present while informal activities are those with no instructor present. Questions appearing in the NCES materials include “What is the highest grade or year of school that you completed?,” “Do you have/Did you later receive a high school diploma or its equivalent, such as a GED?,” and “Did you work at a job for pay or income at any time in the past 12 months, including self-employment?,” among others. Certain response patterns suggest different levels of adult involvement in learning activities, different reasons for taking courses, and an employer’s financial contribution to the adult’s learning activity. Next, several variables in the AE data consistent with Hauser and Warren’s^{Error! Bookmark not defined.} definition based on householder occupation, education, and income were identified. Examples of candidate AE variables for an SES measure for this survey included: 1) Educational Level (Highest grade/YR completed and HS diploma or GED); 2) Occupational Status (Year last worked for pay or income / Hours worked per week); and 3) Income (Total household income range / Currently works for employer / Amount of earnings). The availability of multiple variables reflecting, for example, educational level, strengthens the analyses because these serve as “items” and having multiple items assessing the same facet should ultimately increase the reliability and ideally the validity of the SES measure.

EFA of AE variables deemed to be consistent with Hauser and Warren’s^{Error! Bookmark not defined.} facets of SES (including those above) to preliminarily identify SES factors using SPSS version 20³¹ were performed. These analyses provided evidence of an identifiable SES factor structure corresponding to household educational level and income.

The last step involved developing conceptual and empirical arguments about the extent to which a factor supports valid inferences about household SES for the AE. This focused on assessing construct validity using a combination of two complementary lines of evidence. The first is the agreement between the factor analytic findings and the conceptualization of SES attributed to Hauser and Warren.^{Error! Bookmark not defined.} Specifically, the emergence of identifiable SES factors corresponding to householder occupational status, education, and/or income provides evidence that NHES survey respondents can be placed in a hierarchical order and thus indicates construct validity. The second line of evidence comes from correlations between the derived factors and other variables in the AE survey.

RESULTS

Adult Education/Adult Education and Lifelong Learning (AE/AELL, 2005)

The AE/AELL survey (see Table 1) was based on 8,904 adults, with respondents ranging from 6,697-19,722 non-institutionalized adults aged 16 and older, not enrolled in 12th grade or below, and not on active duty in the US armed forces.

AE/AELL items	Factor loading		
	1	2	3
Factor 1: Education Related to Employment			
Earned college credit	.98	-.05	.07
Meet requirements for public assistance	.98	-.05	.07
Attend college or vocational school	.98	-.05	.07
Get a raise or promotion	.98	-.05	.07
Get a new job	.97	-.05	.07
ESL for work or personal reasons	.96	-.04	.07
Currently taking ESL classes	.95	-.04	.07

AE/AELL items	Factor loading		
	1	2	3
Instruction provider was employer	.70	-.02	.04
Work while taking ESL classes	.69	-.02	.04
Employer required to take ESL classes	.68	-.01	.04
Being paid while taking ESL classes	.68	-.02	.04
Employer suggested to take ESL classes	.65	-.01	.03
Total hours attending ESL classes	.58	-.03	.02
Factor 2: Higher Educational Attainment			
Type of program-professional degree	.03	.97	-.06
Get/keep certificate or license	.03	.97	-.06
Type of degree-another degree	.03	.97	-.05
Type of program-doctorate	.03	.96	-.06
Type of program-master's degree	.03	.93	-.06
How long enrolled in program	.03	.92	-.06
Type of program-bachelor's degree	.03	.92	-.05
Type or program-associate's degree	.03	.92	-.05
Total credit hours enrolled	.02	.75	-.05
Factor 3: Lower Educational Attainment			
Basic skills classes	.06	-.08	.99
Other high school equivalency program	.07	-.08	.99
GED preparation classes	.07	-.08	.99
Ever taken ABE/GED classes	.03	-.08	.95
Has high school diploma or GED	.02	.01	.66
Actual grade 9–11 completed	.02	-.05	.54
Actual grade 0–8 completed	.04	-.05	.52
Took ESL classes	.12	-.01	.33
Ever taken ESL classes	-.06	-.00	.31

Note: N = 8,904. Items with factor loadings < .3 are omitted. Bold indicates a factor loading above .3 and to indicate which factor (1, 2 or 3). ESL = English as second language; ABE = Advanced basic English classes.

Table 1. *Adult Education/ Adult Education and Lifelong Learning (AE/AELL; 2005) survey*

The three factors to emerge were “Education Related to Employment” (factor 1), “Higher Educational Attainment” (factor 2), and “Lower Educational Attainment” (factor 3), with results representing a pattern that is partly consistent with the conceptualization of SES as having an educational facet.

Before and After School Programs and Activities (ASPA; 2005)

The ASPA (see Table 2) sample of 11,684 is nationally representative of non-institutionalized students enrolled in kindergarten through eighth grade with a maximum age of 15 years.

ASPA items	Factor loading		
	1	2	3
Factor 1: Father’s Educational Attainment			
Dad enrolled in school	.93	-.29	-.02
Education attainment of child’s father/guardian	.93	.13	-.03
Months dad worked in past year	.88	-.15	-.02
Highest grade/yr of school dad completed	.87	.23	-.03
Dad worked for pay last week	.84	-.34	-.01
Hours per week dad works for pay	.79	-.08	-.02
Work status of dad/stepdad/foster dad/guardian	.72	-.36	-.01
Dad’s ease of leaving work	.69	-.07	-.00
Household income below or above \$50K	.55	.38	-.02
Total household income range	.50	.32	-.01
Family received Medicaid in past 12 months	.40	.28	-.03
Family received food stamps in past 12 months	.38	.20	-.03
Factor 2: Mother’s Educational Attainment			
Highest grade/yr mom completed	.30	.79	-.03
Highest level of parent/guardian education	.50	.75	-.04
Educational attainment of child’s mother/guard	.28	.77	-.03
Actual grade 0-8 mom completed	-.12	-.38	.00
Actual grade 9-11 mom completed	-.19	-.30	.01
Months mom worked in past year	-.00	.30	.05
Hours per week mom works for pay	-.04	.29	.08
Mom has high school diploma or GED	-.23	-.37	.00
Factor 3: Type of Financial Childcare Support Household Received			
TANF helps pay for relative care	-.06	-.00	.99
Other helps pay for relative care	-.06	-.00	.99
Social services/welfare helps pay for care	-.06	.00	.99

Note: N = 11,684. Items with factor loadings < .3 are omitted. Bold indicates a factor loading above .3 and to indicate which factor (1, 2 or 3); TANF = Temporary Assistance for Needy Families

Table 2. Results from the Before- and After-School Programs and Activities (ASPA; 2005) Survey

The first factor was defined by “Father’s Educational Attainment”. The second factor contained variables loading highly on a component of mother or mother-figure’s education, resulting in “Mother’s Educational Attainment.” The third factor was labeled “Types of Financial Childcare Support a Household Received.”

Early Childhood Program Participation (ECPP, 2005)

The ECPP survey (see Table 3) used interviews with 7,209 parents of children aged three through third grade, children from birth through age six, and those not yet in kindergarten.

ECPP items	Factor loading		
	1	2	3
Factor 1: Father's Educational Attainment			
Educational Attainment of child's father/guardian	.99	.08	-.04
Highest grade/yr of school dad completed	.97	.05	-.03
Dad enrolled in school	.75	.12	-.05
Months dad worked in past year	.74	.12	-.03
Dad worked for pay last week	.70	.10	-.05
Highest level of parent/guardian education	.69	-.08	-.02
Hours per week dad works for pay	.65	.14	-.03
Work status of dad/stepfather/fosterdad/guard.	.59	.06	-.05
Dad's ease of leaving work	.57	.06	-.02
Household income below or above \$50K	.54	-.15	-.01
Total household income range	.47	-.14	-.00
Family received Medicaid in past 12 months	.47	-.14	-.01
Family received WIC in past 12 months	.41	-.13	-.02
Family received food stamps in past 12 months	.40	-.08	-.02
Own or rent home or other arrangement	-.39	.08	.03
Percent under 18 below poverty line	-.35	.04	.05
Factor 2: Mother's Work Status			
Work status of mom/stepmom/fostermom/guard.	-.04	.97	-.03
Mom looking for work in past four weeks	-.05	.95	-.03
Mom worked for pay last week	-.09	.85	-.02
Hours per week mom worked for pay	-.02	.84	.05
Mother/guardian works full time	-.02	-.84	.05
Mom's ease of leaving work	.05	-.80	.05
Months mom worked in past year	.06	-.77	.05
Factor 3: Type of Financial Childcare Support Household Received			
Other helps pay for relative care	-.06	-.11	.98
TANF helps pay for care	-.06	-.11	.98
Social services/welfare helps pay for care	-.05	.11	.98

Note: N = 7,209. Items with factor loadings < .3 are omitted. Bold indicates a factor loading above .3 and to indicate which factor (1, 2 or 3)

Table 3. Results from a factor analysis of the Early Childhood Program Participation (ECPP; 2005)

The first factor was indicated by items which loaded highly on a latent variable again labeled “Father’s Educational Attainment.” The second was labeled “Mother’s Work Status” as it related to the employment status and hours of the mother in a household. The third factor was indicated by high loadings on items related to employer, state, or other sources of financial aid and was labeled “Type of Financial Childcare Support a Household Received.”

Parent and Family Involvement in Education (PFI; 2007)

The PFI survey (see Table 4) was completed with the parents of 10,681 children in kindergarten through 12th grade.

PFI items	Factor loading		
	1	2	3
Factor 1: Father’s Educational Attainment			
Dad enrolled in school	.98	-.05	-.02
Dad worked for pay last week	.87	-.10	-.00
Months dad worked in past year	.86	.01	-.04
Educational attainment of child’s resident dad/guardian	.86	.20	-.03
Highest grade/yr dad completed	.78	.26	-.03
Work status of dad/stepdad/foster dad/guard.	.76	-.13	.00
Hours per week dad works for pay	.74	.05	-.03
Factor 2: Mother’s Educational Attainment			
Educational attainment of child’s resident mom/guardian	.11	.97	.01
Highest grade/yr mom completed	.13	.97	.01
Mom enrolled in school	-.03	.43	-.00
Months mom worked in past year	-.06	.34	-.02
Mom has high school diploma or GED	-.13	-.30	.01
Actual grade 0-8 mom completed	-.06	-.30	-.02
Factor 3: Type of Financial Support Household Received			
Receives services from other source	-.03	-.01	.99
Receives services from state/local/social services	-.03	.00	.98

Note. N = 10,681. Items with factor loadings < .3 are omitted. Bold indicates a factor loading above .3 and to indicate which factor (1, 2 or 3)

Table 4. Results from a factor analysis of the Parent and Family Involvement (PFI; 2007) Survey

The factor loadings for the PFI survey suggested an initial factor was once again labeled “Father’s Educational Attainment,” with a few income-related variables and the pattern of loadings for the second factor led to the label “Mother’s Educational Attainment.” Lastly, factor three was labeled “Type of Financial Support a Household Received.”

School Readiness (SR; 2007)

The SR survey data (see Table 5) were provided by 2,633 children aged 3-6 and kindergarten through second grade.

School readiness items	Factor loading		
	1	2	3
Factor 1: Father’s Educational Attainment			
Educational attainment of child’s resident dad/guardian	.99	-.11	-.03
Highest grade/yr dad completed	.97	.09	-.02
Dad enrolled in school	.74	.08	-.02
Months dad worked in past year	.73	.12	-.04
Dad worked for pay last week	.70	.08	-.01

Hours per week dad works for pay	.64	.14	-.04
Work status of dad/stepdad/foster dad/guard	.57	.04	.00
Factor 2: Mother's Work Status			
Work status of mom/stepmom/foster mom/guardian	-.04	.99	.02
Mom looking for work in the past four weeks	-.05	.92	.01
Mom worked for pay last week	-.10	.87	.01
Mom/guardian works full time	-.01	.86	.02
Hours per week mom works for pay	.01	-.83	-.02
Months mom works in past year	.03	-.72	-.02
Factor 3: Type of Financial Support Household Received			
Receives state/local/social services	-.04	.03	.99
Receives services from other source	-.05	.03	.98

Note. N = 2,633. Items with factor loadings < .3 are omitted. Bold indicates a factor loading above .3 and to indicate which factor (1, 2 or 3)

Table 5. Results from a factor analysis of the School Readiness (SR; 2007) Survey

A pattern of loadings similar to other surveys led to labeling the first factor for SR “Father’s Educational Attainment,” although a few items were inconsistent. The other factors were labeled “Mother’s Work Status” and “Type of Financial Support a Household Received.”

Early Childhood Program Participation (ECPP; 2019)

The ECPP (see Table 6) contained a total of 7,092 participants who were parents of children aged three through third grade, children from birth through age six, and those not yet in kindergarten.

ECCP items	Factor loading		
	1	2	3
Factor 1: Socioeconomic status as it relates parent/guardian employment status			
First parent/guardian employment status	-.53	.10	.07
Factor 2: Socioeconomic status as it relates to household total income			
Total income	-.08	.90	.25
Factor 3: Socioeconomic status as it relates to household receiving public assistance			
Received food stamps in past 12 months	-.03	-.12	.55

Note. N = 7,092. Items with factor loadings < .3 are omitted. Bold indicates a factor loading above .3 and to indicate which factor (1, 2 or 3)

Table 6. Results from a factor analysis of the Early Childhood Program Participation (ECPP; 2019) Survey

Three factors emerged as salient after factor analysis. Factor 1 related to employment status and months and hours worked. Factor 2 is concerned with socioeconomic status as it relates to household total income. Factor 3 related to receiving public benefits and correlates with total income.

Parent and Family Involvement (PFI, 2019)

The PFI (see Table 7) had a total of 14,075 participants and surveyed children in kindergarten through 12th grade.

PFI items	Factor loading	
	1	2
Factor 1: Socioeconomic status as it relates to age respondent became a parent		
First parent/guardian age when became parent	.86	-.03
Factor 2: Socioeconomic status as it relates to number of hours worked by first parent/guardian		
First parent/guardian hours worked per week	.03	.53

Note. N = 14,075. Items with factor loadings < .3 are omitted.

Table 7. Results from a Factor Analysis of the Parent and Family Involvement (PFI; 2019) Survey

Two factors emerged from this analysis. Factor 1 was the most salient and related to the age the participant became a parent, which related directly to SES and grade level completed. Findings also showed a relationship between hours a parent worked and highest grade level completed. Factor 2 related to hours worked. Thus, the age when the participant became a parent may have impacted their educational level.

Validity Evidence

This research operationalizes SES according to the multidimensional approach suggested by Hauser and Warren¹, in which SES is considered a latent variable encompassing householder occupation, education, and income. This is consistent with identified factors such as "Father's Educational Attainment" and "Type of Financial Support a Household Received," which correspond directly to Hauser and Warren's conceptualization of SES. This helped us to ensure a comprehensive approach to SES, better catching its complex nature than the one-dimensional measures discussed earlier.

Further empirical evidence of validity is provided by a more detailed examination of the factor loadings and items, or, in other words, the bivariate correlations of the actual items and factors obtained. Several items from each survey were compared with their associated factors. To begin, the AE/AELL 2005 survey displayed a first factor that was labeled "Education Related to Employment." Its bivariate Pearson correlations with similar items were high. For example, a .98 correlation was found between this factor and the items "Earned college credit" and "Get a raise or promotion" as reasons for the outcomes of pursuing after-school education.

The second factor in this survey was labeled "Higher Educational Attainment." As such, it had a strong correlation with items such as "Earned college credit" at .97. However, this factor correlated at -.04 with items such as "Took basic skills classes" and "Took GED prep classes," items it was not expected to correlate with. Lastly, factor three was labeled, "Lower Educational Attainment." In this case, the opposite effect was observed. Higher correlations were observed for items related to lower educational attainment, whereas higher educational attainment correlated negatively. For example, the item labeled, "Grade 9-11 completed" correlated with this factor at .54. Bivariate correlations provide evidence of an educational component within the NHES survey database. This educational component can be ranked hierarchically, and thus can be used in mapping it onto the educational component of Hauser and Warren's^{Error! Bookmark not defined.} definition.

Next, the first factor in the ASPA 2005 survey was labeled, "Father's Educational Attainment." Evidence for this was the fact that correlations between this latent factor and the items "Dad enrolled in school" and "Work status of dad/step/fosterdad/guardian" were high at .93 and .72 respectively. However, low correlations appeared for items related to mother's educational attainment. High correlations appeared for this factor among items related to father's enrollment in school, educational attainment, months work, highest grade completed, worked last week, hours worked and work status, income, and financial support household received. These items will be discussed later.

The second factor in this survey was labeled, "Mother's Higher Educational Status." Items correlating strongly with this factor included "Highest grade/yr mom completed", "Highest level of parent/guardian education" and "Educational attainment of child's mother/guardian" at .79 to .77 respectively. However, items that showed a weak correlation involved mother's lower educational attainment as well as father's educational status and items related to mother's work status. These correlations provided further validity evidence for the specific label of this factor. Negative loadings were found for the items "Actual grade 0-8 completed," "Actual grade 9-11 completed," and "Mom has high school diploma or GED". These items likely have negative loadings because they oppose the second factor. These items contain lower values for the factor "mother's educational attainment," while positive loadings would correspond to higher levels of educational attainment (e.g., some college, college degree).

The third factor was labeled “Types of Financial Childcare Support Household Received.” Correlations in the .99 range were found for items related directly to childcare householder support. However, other types of financial support such as the household receiving support from WIC in the past 12 months and whether the family receives support from state, local, or social services was unrelated to this third factor. Like the AE survey, an educational element emerged that can be ranked vertically (high/low). A financial component also emerged that related to financial support a household receives for childcare. This factor is positioned as a strong link to Hauser and Warren’s Error! Bookmark not defined. component of SES involving income; for example, a household requiring financial support for childcare may rank lower in income.

The ECPP 2005 survey displayed similar corroboration between factors and items. Factor one was labeled “Father’s Educational Attainment” and correlated strongly at .97 with the item “Highest grade/yr of school dad completed,” but at .50 with the respective item related to the mother’s highest grade/yr of school completed. This is an indication that the item was related to the father’s educational attainment and not the mother’s. However, items related to father’s work status also correlated strongly with this factor. The negative factor loadings for “Own or rent home or other arrangement” and “Percent under 18 below poverty line” suggest that these items are inversely related to the underlying factor of “Father’s Educational Attainment.” Homeownership is associated with a lower number, thus it is positively skewed and generating a negative factor. Percentage of children living below the poverty line represents a socioeconomic disadvantage that contrasts with the positive socioeconomic indicators linked to higher education.

Next, the second factor was labeled “Mother’s Work Status” and correlated strongly on items related specifically to this factor such as “Mom worked for pay last week” at .85, but showed a weaker correlation on items related to the number of hours the father works for pay at .14, demonstrating that this factor pertained specifically to a mother’s work status. This item correlated weakly or negatively with items related to income or household financial support. A factor such as “Mother’s Work Status” permits a connection between this factor and Hauser and Warren’s Error! Bookmark not defined. definition as having an “occupation” component. Future research might examine the precise ranking of this factor. Some negative loadings were found for the second factor labeled, “Mother’s work status”; specifically, the items: “Mother/guardian works full time”, “Mom’s ease of leaving work” and “Months mom worked in past year.” These are negative because they have an inverse relationship to the theme of this factor. These items are ranked with multiple options for the employment values, potentially reflecting the opposite endorsement pattern. Lastly, factor three, called “Types of Financial Childcare Support Household Received,” correlated positively with the three types of financial support for childcare that this survey examined. However, it, correlated in the low or negative range for items related to state support, educational attainment and parent’s work status, and questions related to income.

Next, the PFI 2007 survey demonstrated similar evidence of validity. For example, the first factor was labeled “Father’s Educational Attainment.” An item that correlated highly with this factor was, for example, “Educational attainment of child’s resident dad/guardian” at .86, but another item called, “Highest grade/yr mom completed” correlated at only .13, indicating that this factor pertained most significantly to the householder father’s educational attainment. It should be noted that high correlations appeared for this factor among items related to a father’s work status, indicating that this factor may not only relate to father’s educational attainment, but may also have an educational component. Again, these discrepancies will be unpacked in the discussion section. The second factor of “Mother’s Educational Attainment” loaded high on “Highest grade/yr mom completed” at .97, but low on an item related to the father’s school status, “Dad enrolled in school,” at -.05. This evidence suggests that the factor pertained to the householder mother. Lastly, the third factor, called “Type of Financial Support Family Received,” correlated very strongly with the items related to a family’s sources of financial support, but in the negative range on items related to parental education and work status. Like the ASPA 2005 survey, the PFI 2007 survey consisted of 2 items that loaded negatively, “Mom has HS diploma or GED” and “Actual grade 0-8 mom completed”. Again, these items may have negative loadings because these two variables are associated with lower educational attainment.

As discussed among the results of the previous surveys, the father and mother’s educational attainment provides a direct connection to the educational component of SES. Reflecting similar connections as the financial childcare support a family receives as found in the ASPA and ECPP surveys, “Type of Financial Support a Household Received” supplies a factor that again maps onto the “income” component of SES as used in this paper.

The first factor in the SR 2007 survey was labeled, “Father’s Educational Attainment.” Validity evidence for this factor came from high correlations among items relating to it such as “Educational attainment of child’s resident dad/guardian” at a .99 correlation and “Dad enrolled in school” at .74. However, items that correlated lower with this factor are those related to the educational status of the mother. Items related to family financial support correlated in the negative range for this factor. This provided further empirical evidence that this factor, in fact, relates to a father’s educational attainment and was thus named appropriately.

However, items related to the father's number of paid work hours and the father's work status also demonstrated high correlations.

A second factor was labeled "Mother's Work Status." Items correlating strongly were directly related to the householder mother's work status, indicating whether she is employed but not work duration. A negative correlation appeared for items related to duration of work such as "Hours per week mom work for pay" at -.83. Items related to householder father's work status and duration all demonstrate low or negative correlations, adding further evidence that this factor was related to the householder mother. Two negative loadings emerged in this pattern of factor analysis, "Hours per week mom works for pay" and "Months mom works in past year". This may indicate different employment patterns or job stability compared to the other items. To conclude, the last factor in this survey was called, "Type of Financial Support Household Received." Items directly related to this type of support correlated above .90, such as "Receives state/local/social services" which correlated at .99. "Father's Educational Attainment," "Mother's Work Status" and "Type of Financial Support a Household Received" grant direct links to each element of Hauser and Warren's [Error! Bookmark not defined.](#) definition of SES.

The ECPP 2019 survey had one item load as negative, "First parent/guardian employment status" at -.53. This negative loading might represent that this item's particular employment status (such as unemployment or irregular employment) is associated with lower socioeconomic status. This negative loading could indicate that less stable or non-standard employment of the first parent/guardian is inversely related to higher socioeconomic status, reflecting economic instability or disadvantage. Because only one item per factor loaded above .30, the ECPP 2019 survey may be a weak proxy for SES.

The PFI 2007 survey does not contain any negative loadings; however, again, because only one item per factor loaded above .30, the PFI 2019 survey may be a weak proxy for SES.

DISCUSSION

Results suggest that conceptually and psychometrically rigorous measures of SES should be constructed for the NHES survey database. This would likely enhance inferences based on these data and increase the appeal of the database to the wider educational research community. For example, Breit-Smith *et al.*³² utilized the 2005 administration of the ECPP survey in the NHES survey database to investigate children with a developmental disability, children with a single disability in comparison to children with multiple disabilities, and speech language disability. The results of the study indicate that it is crucial to take emerging literacy and home literacy experiences into account when evaluating the talents of young patients with disabilities and making clinical recommendations. In another study, Park *et al.*³³ used the 2005 NHES survey ASPA survey to investigate Latino immigrant children who are disadvantaged and vulnerable due to their limited English skills and a lack of educational resources. The findings prompt consideration of whether standard after-school programs are suitable for Latino children from immigrant homes. Further, these findings emphasize the necessity of including culturally appropriate elements in the curriculum for regions with a high concentration of Latino immigrant households.

Analyses of the NHES surveys produced results consistent with the educational facet and, to a lesser extent, the occupational facet. Generally, items correlated highly with factors they would be expected to correlate with, and vice versa. The survey data have further applications if used as proxy measures of SES by educational researchers such as in the exploration of such questions as whether parents with a higher income are more likely to be involved in their child's homework.³⁴

Using Hauser and Warren's [Error! Bookmark not defined.](#) multidimensional conceptualization of SES involving the facets of householder education, occupation, and income, analyses of the NHES surveys produced results generally consistent with the educational facet and the occupational facet. Factors labeled "Father's Educational Attainment," "Mother's Educational Attainment," "Mother's Work Status," "Type of Financial Support a Household Received," and "Type of Financial Childcare Support a Household Received" appeared consistently across surveys. This consistency of socioeconomic factors provides preliminary evidence of construct validity.

Further evidence of construct validity was provided through an examination of the bivariate correlations between the factors and the items in each survey. Primarily, items correlated highly with factors they would be expected to correlate with, and the same can be said for low correlations. However, some items related to the factor "Father's Educational Attainment" presented a special challenge. While this factor correlated strongly (above .95) with items directly related to this construct such as father's work status, number of hours worked, a father's income and household financial support, its correlation with other items such as "Mom has high school diploma or GED," "Mother's Work Status," and "Type of Financial Support a Household Received" were problematic. In this preliminary exploratory analysis, the factor structure found was coherent overall, but the discrepancies found require further study.

An interesting feature of the results, with the exception of the AE survey, was the appearance of a factor characterizing the type of financial support received. This variable was composed of employer, state, and other support sources and may turn out to be a

suitable measure of the income component of SES as research continues to show that it is generally inappropriate to use direct measures of income, such as earnings.¹⁷

Our findings confirm the utility of Hauser and Warren's multidimensional operationalization of SES for capturing these nuances. There are other operationalizations that provide useful light, focusing on single indicators such as parental education or geographic location, for example, but which could not capture the breadth and complexity of socioeconomic factors addressed by Hauser and Warren's model. The use of a multidimensional approach in this study underlies the robustness and theoretical grounding for the analysis of SES.

Number of Factors Extracted

Upon examining the surveys that were able to produce two, three or four factors, in part based on the interpretation of the scree plot, utilizing three factors permitted the clearest solution in terms of its application to an SES construct. To examine this empirically, EFA was conducted specifying the extraction of two, three or four factors. For example, in relation to the ECPP 2005 survey, EFA specified the extraction of two factors. The result was that the first factor grouped items related to father and mother's educational attainment, father's work status, and types of financial support a household receives. The second factor included items related to financial childcare support such as Temporary Assistance for Needy Families. Items related to mother's work status did not load high enough (above the .30 threshold) to be included.

Performing EFA on the ECPP 2005 survey for four factors grouped variables related to father's educational attainment and father's work status as factor one while factor two clearly delineates items related to mother's work status. Factor three appeared to group items related to father and mother's educational attainment, income range, and household financial support. This factor may be combined to a factor that can be called "earning potential" or "income." Factor four was a mixture of other items and difficult to define. In short, a three-factor solution provided the clearest factor structure and factor interpretation for the 2005 and 2007 surveys, while a two-factor solution appeared most suitable for the 2019 NHES surveys.

Although a four-factor deduction of the items on the ECPP 2005 survey lends itself to an expanded conceptualization of factors that can be mapped on to the components of Hauser and Warren's *Error! Bookmark not defined.* definition and may be ranked hierarchically, it is cumbersome, especially given the nature of factor three. Although the scree plot for this ECPP survey suggests four factors, examining the survey with two or four factors does not allow the factors to be examined in a more detailed manner, which aids in applying the factors theoretically to Hauser and Warren's *Error! Bookmark not defined.* definition. However, the importance of a solution consisting of four factors should not be understated, and such a solution may prove useful in future research such as when exploring alternative definitions and conceptualizations of SES, such as in the field of sociology when considering facets of social stratification or social mobility. However, in this research, the fourth factor was set aside temporarily in favor of the three-factor solution with the specific focus on Hauser and Warren's *Error! Bookmark not defined.* definition of SES.

LIMITATIONS

One limitation was that the 2005 and 2007 surveys contained more items that factor loaded and correlated with one another and, thus, exhibited stronger themes related to SES. However, with the two 2019 surveys (ECPP and PFI), factor loadings were lower, and it was more difficult to determine which factors emerged as prominent. Although the SES factors were similar across all surveys, the 2019 surveys had two factors while the 2005 and 2007 surveys had three. In terms of participants, the surveys had an adequate sample size and a diverse sample of the US population. Future educational researchers may build on this work to further explore these datasets and adjust what items to include, as well as explore alternative rotation and extraction methods.

CONCLUSIONS

Overall, the NHES survey database has much to offer educational researchers because of its detailed focus on pre-primary education, childcare utilization, school safety and discipline, and adult education. For example, the ECPP survey from the 2005 NHES survey database was investigated to explore whether there was a difference in home literacy practices, and emergent literacy skills of children with and without developmental disabilities.³² Furthermore, Constanzo and Magnuson³⁵ use the NHES survey ECPP data to examine differences in childcare arrangements between families with children who have a disability and families with children who do not. Using the NHES surveys as a proxy measure of SES may lend itself to using SES-related variables as indicator variables in statistical models. For example, using a similar database to examine if SES is a hidden factor behind four indicators (poverty ratio, personal earnings, educational attainment, and employment status), Martinez *et al.*³⁶ analyzed data from the 2013 National Health Interview Survey. In a second example, Avvisati³⁷ reviewed measures and indicators of SES in PISA, a large-scale international assessment of student achievement. Their findings explore the basis for the construction of a composite measure of SES in PISA and other large-scale surveys. Furthermore, SES is a crucial factor affecting psychological well-being and academic achievement and should be considered when designing educational programs and curriculum (Navarro-Carrillo *et al.*, 2020).³⁸ For these reasons, increased research on the correlations between SES and education is essential.

As this work was exploratory in nature, our aim was to examine what factors emerged from the analyses of the seven surveys described in this work to explore the extent to which these factors could be used as proxy measures for SES. Further research could capitalize on these results and examine alpha reliability tests of the factors that were included. The benefit of an alpha reliability analysis is to strengthen the argument that certain items act as a proxy measure for SES. An SES proxy instrument using alpha reliability analysis would help indicate the degree to which lower-level factors are impacting the overall factor. Consequently, lower-level factors could potentially be dropped, and the alpha reliability analysis further examined.

By adhering to the definition of SES provided by Hauser and Warren, we were better placed to clearly link the variables explored in the NHES surveys and SES. This is because some studies may use narrow operationalizations, which emphasizes the relevance of choosing a model representing the complexity of socioeconomic factors. Future studies on SES should be done with continued attention to this multidimensionality, for it accommodates a better grasp of the effects of these indicators on educational outcomes.

Our results support the argument that conceptually and psychometrically rigorous measures of SES can be developed in most of the NHES surveys. However, the ECPP and PFI 2019 surveys demonstrated a weak ability to act as proxy measures of SES due to less factor loadings. The results, while preliminary, suggest that rigorous measures of SES can be constructed based on Hauser and Warren's¹ model which used income, education, and occupation. The availability of such measures should enhance inferences based on these data and simultaneously increase the appeal of this database to the educational research community.

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PRESS SUMMARY

Researchers have successfully developed robust measures of socioeconomic status (SES) for the National Household Educational Surveys (NHES). By employing rigorous methods, they found that measures based on income, education, and occupation enhance the understanding of educational dynamics. This research promises to deepen insights into diverse educational phenomena, from early childhood programs to adult learning. By bridging theory with empirical analysis, this work amplifies the significance of NHES data for educational research, offering valuable tools to explore the intricate relationship between SES and educational outcomes.

Bavachin Suppresses Cell Growth and Enhances Temozolomide Efficacy in U-87 MG Glioblastoma Cells

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ABSTRACT

Glioblastoma multiforme (GBM) is a lethal cancer affecting the central nervous system. Existing treatment methods for GBM include chemotherapy, radiation, and surgery. Temozolomide is a common chemotherapy treatment for GBM but causes unwanted side effects, as do most chemotherapy treatments. To decrease the harmful side effects of chemotherapy, research has turned to exploring natural compounds to treat cancer. In this study, the natural compound bavachin was investigated to determine cytotoxicity in GBM cells. Bavachin has been tested in many cell lines but not glioblastoma. A sulforhodamine B (SRB) assay, trypan blue counting, and a tumorsphere assay were used to test the hypothesis in this study. It was found that bavachin suppressed glioblastoma cell and tumorsphere viability, had a synergistic interaction with temozolomide, and ornithine decarboxylase was identified as a potential target *in silico*. This study demonstrated the ability of bavachin to suppress the growth of U-87 MG glioblastoma cells and enhance temozolomide efficacy. These findings demonstrated that bavachin is a potential treatment for GBM based on its ability to suppress cell growth.

KEYWORDS

Glioblastoma Multiforme; Temozolomide; Bavachin; Flavonoid; Tumorspheres; Cell Viability; Cancer; Apoptosis; *Psoralea corylifolia*

INTRODUCTION

Glioblastoma multiforme (GBM) is one of the most aggressive cancers with a high rate of treatment resistance. Glioblastoma begins as an abnormal growth of astrocytes that eventually crowds and harms healthy tissue. Astrocytes are a type of glial cell in the central nervous system that forms scar tissue to repair the brain when damaged. Glioblastomas are classified as IV-grade astrocytoma tumors by W.H.O. due to their fast growth and are the most common malignant brain tumors in adults.¹ Although the risk of forming glioblastoma is low, in 2023 the American Cancer Society predicted 24,810 malignant tumors diagnoses and 18,990 deaths that year from glioblastoma.¹

The known forms of treatment for GBM include chemotherapy, radiation, and surgery. Chemotherapy with temozolomide (TMZ) is commonly used to treat GBM, but GBM rarely responds to treatment.² TMZ is an imidazotetrazine lipophilic prodrug that can cross the blood-brain barrier and is administered orally. TMZ is activated at physiological pH through conversion to the metabolite 5-(3-methyltriazin-1-yl) imidazole-4-carboxamide (MTIC). MTIC is then hydrolyzed to produce methyl diazonium, which damages DNA by forming multiple DNA adducts. These adducts create an opportunity for mismatched base pairing.³ While survival rates have improved, individual variability remains significant with average survival extending from ten to fourteen months post-diagnosis.³ Resistance to TMZ develops quickly due to widespread exposure and DNA repair mechanisms. Cells contain DNA repair mechanisms that detect and correct mismatched bases to prevent apoptosis. As methyl diazonium ions are added, O6-methylguanine adducts are generated. O6-methylguanine-DNA methyltransferase (MGMT) works to counteract the damage done by O6-methylguanine.⁴

Effective treatment for GBM remains a formidable challenge in molecular oncology, with high-grade gliomas exhibiting unfavorable outcomes despite advances in diagnosis and therapy. GBM treatment is further complicated by factors such as the advanced age of onset, tumor location, and incomplete understanding of the tumor's pathophysiology.⁵ Due to the limitations of current treatments, including their potential to harm healthy cells, naturally-occurring compounds are becoming a popular focus of study in many cancers including GBM. Various natural compounds such as flavonoids, polyphenolic compounds, curcumin,

icariin, and others exhibit anticancer potentials through different mechanisms such as induction of apoptosis, inhibition of angiogenesis, modulation of intracellular signaling pathways, and inhibition of cell proliferation.⁶⁻¹⁰

Flavonoids are found in many fruits, vegetables, and other vascular plants. While flavonoids can adversely affect bacteria, viral enzymes, and pathogenic protozoans, they show little toxicity in animals. Flavonoids have been studied as herbal medical treatments for decades and used for much longer. It has been determined that flavonoids inhibit certain enzymes, mimic some hormones (including estrogen), and scavenge free radicals.¹¹⁻¹³ Additionally, flavonoids inhibit malignant cell proliferation by directly inhibiting mitosis. One promising flavonoid to inhibit GBM cell growth is bavachin. It is isolated from the fruit of *Psoralea corylifolia*, Fructus Psoraleae, a legume native to China.¹⁴ In contrast to TMZ, bavachin is a natural compound that has been shown to target cancer cells more specifically. Bavachin is currently being explored for its anti-cancer effects and has been tested in multiple cancer cell lines including oral, bone, multiple myeloma, choriocarcinoma, colorectal, and liver. In each of these studies, bavachin was shown to induce apoptosis.^{6, 15-18}

This research study focused on the apoptotic effects of the flavonoid bavachin in the GBM cell line, U-87 MG. This study implemented SRB, trypan blue, and tumorsphere assays for measuring cell viability in response to bavachin treatment. Additionally, molecular docking software was used to create an *in silico* model of bavachin bound to ornithine decarboxylase. Finally, U-87 MG cells were treated with bavachin and TMZ together to evaluate the combined drug interaction. We hypothesized that bavachin would limit cell viability, inhibit tumorsphere growth, and induce apoptosis in the glioblastoma cell line, U-87 MG, by inhibiting ornithine decarboxylase.

METHODS AND PROCEDURES

Cell Culture

U-87 MG cells (ATCC, Manassas VA, USA) were cultured in Eagle's Minimum Essential Media (Corning, Corning NY, USA) with penicillin-streptomycin (200 IU/L) (Corning) and 10% fetal bovine serum (ThermoFisher Scientific, Waltham MA, USA). Cells were left to grow and proliferate for at least two days at 37 °C, 100% humidity, and 5% CO₂ before experimentation. Once cells reached 70% confluence, the cell medium was aspirated; cells were washed with warm PBS (ThermoFisher), and two mL of trypsin (ThermoFisher) were added to lift the cells for five minutes at 37 °C. The trypsin was neutralized with eight mL of media and collected cells were briefly vortexed before counting with a hemocytometer. All experiments were conducted using U-87 MG cells within one to five passages from acquisition.

*SRB Viability Assay*¹⁹

Cells (5 X 10³) were seeded in 96 well plates (Genesee Scientific, El Cajon CA, USA) with 100 µL media and allowed to adhere overnight. Then 100 µL of media containing 2X concentration of bavachin (MedChemExpress, Monmouth Junction NJ, USA) or negative control (1% DMSO) (UFC Biotechnology, Buffalo NY, USA) were overlaid in each well for 48 hours. Each well then received 100 µL of 10% w/v cold trichloroacetic acid (ThermoFisher) and was incubated at 4 °C for one hour to fix the cells. Each well was rinsed three times with DI H₂O and stained with 100 µL 0.057% w/v sulforhodamine B (SRB, Sigma-Aldrich) for 30 minutes at room temperature in the dark. Wells were washed four times with 300 µL 1% v/v acetic acid (ThermoFisher), and the remaining SRB stain was solubilized with 200 µL of 10 mM tris buffer, pH 10.5 (ThermoFisher). Absorbance was measured at 564 nm with a SpectraMax 190 Microplate Reader (Molecular Devices, San Jose CA, USA) and normalized to the DMSO control. Cells were also imaged at 40X total magnification with an Olympus BX41 phase contrast microscope (Hachioji, Tokyo, Japan) with an AmScope HD202-MW camera (Irvine, CA USA). Some SRB assays included temozolomide (MedChemExpress) to determine drug synergy.

Trypan Blue Viability Assay

Cells (1 X 10⁵) were seeded in six-well plates (Advangene Consumables, Lake Bluff IL, USA) with two mL of media in each well and incubated at 37 °C overnight to allow cells to adhere. Then, media were removed, and cells were treated with DMSO or 50 µM of bavachin. After 48 hours of treatment, the media were removed, cells were washed with PBS, lifted with trypsin for five minutes, briefly vortexed, and diluted 1:2 into 0.4% (w/v) trypan blue (Sigma-Aldrich, St. Louis MO, USA). The number of viable cells was counted with a hemocytometer.

Tumorsphere Generation

U-87 MG cells were used to generate stem cell spheroids. A low attachment plate method was used to generate spheroids.²⁰⁻²² Cells (5 X 10² in 200 µL media) were seeded in a Sphera low-attachment surface plate (ThermoFisher). The plate contained a hydrophilic polymer coating that lowers attachment and promotes cell aggregation. The low-attachment plate was centrifuged for five minutes at 1250 RPM. The cells were incubated at 37 °C at 5% CO₂ and 100% humidity. Plates were treated four days after seeding. Media was replenished on days 7, 10, and 12 by carefully removing 100 µL of media from each well and adding 100 µL of

fresh media to each well. Spheres were imaged on day 14 using an Olympus BX41 phase contrast microscope at 100X total magnification with an iPhone SE camera (Apple Inc., Cupertino CA, USA). The radius of each tumorsphere was measured. The radius and **Equation 1** were used to determine the volume of the spheres.

$$V = \frac{4}{3}\pi r^3 \quad \text{Equation 1.}$$

Molecular Docking

Molecular docking was used to determine a possible protein target of bavachin. Free software including ZINC20, CB-Dock2, and ChimeraX were used to model and view the *in silico* model. Briefly, ZINC20 was used to provide a list of potential binding targets for bavachin (ZINC ID: ZINC15115057) using the Similarity Ensemble Approach (SEA).²³ Ornithine decarboxylase (ODC) was chosen as the target for docking with bavachin. The crystal structure for ODC was downloaded from the Protein Data Base (PDB: 1D7K) to model bavachin binding in CB-Dock2.^{24, 25} Finally, the bavachin-ODC interaction was visualized using ChimeraX.²⁶

Data analysis

All statistical analyses were performed using GraphPad Prism 10.3.1 and assumed that variance was similar between experimental groups. Sample sizes were a minimum of three independent experiments. Group comparisons were made by one-way ANOVA followed by the Dunnett multiple comparison test. Paired comparisons were conducted by unpaired Student t-test assuming two-tailed distribution. Data are represented as mean \pm SD. Differences were considered statistically significant at * $P < 0.05$, ** $P \leq 0.01$, *** $P \leq 0.0001$, (ns = not significant $P \geq 0.05$) when compared to the negative control, DMSO, throughout all testing. Drug synergy was evaluated using the coefficient of drug interaction (CDI) formula (**Equation 2**). AB is the percent remaining cells of an indicated combination treatment, A is the average percent remaining cells of agent one alone, and B is the average percent remaining cells of agent two alone. A CDI of ≤ 0.7 is considered significantly synergistic; CDI = 1 is additive; CDI > 1.0 is antagonistic.²⁷

$$CDI = \frac{AB}{A \times B} \times 100 \quad \text{Equation 2.}$$

RESULTS

Bavachin Reduces U-87 MG Cell Viability

In this study, a sulforhodamine B (SRB) assay was performed to determine the cell viability of cell line U-87 MG after treatment with seven concentrations of bavachin over 48 hours. As seen in **Figure 1A**, bavachin inhibited cell viability in a concentration-dependent manner. Bavachin concentrations of 1, 10, and 25 μM did not have a significant impact on cell viability. However, significant cell death could be detected starting at 50 μM of bavachin. This assay was used to calculate the half maximal inhibitory concentration (IC_{50}) value, which was determined to be 46.00 μM as shown in **Figure 1B**. Therefore, 50 μM bavachin was used for the subsequent trypan blue assay.

Trypan blue only stains dead cells because it is non-permeable to the cell membrane, so it can only enter cells when they are late-stage apoptotic. This assay allowed apoptotic cells to be counted and compared to the total cells counted. Staining with trypan blue after bavachin treatment showed significant cell death and apoptosis compared to the negative control, DMSO, as seen in **Figure 1C**. Not only did we see a comparable reduction in cell viability in the trypan blue assay compared to the SRB assay, but we found the bavachin-treated group contained 18% apoptotic cells (**Figure 1D**). Phase-contrast microscopy in **Figure 1E**, **Figure 1F**, and **Figure 1G** visualized bavachin's ability to suppress growth and cause cell death at 50 μM and 200 μM compared to the control cells with only 1% DMSO.

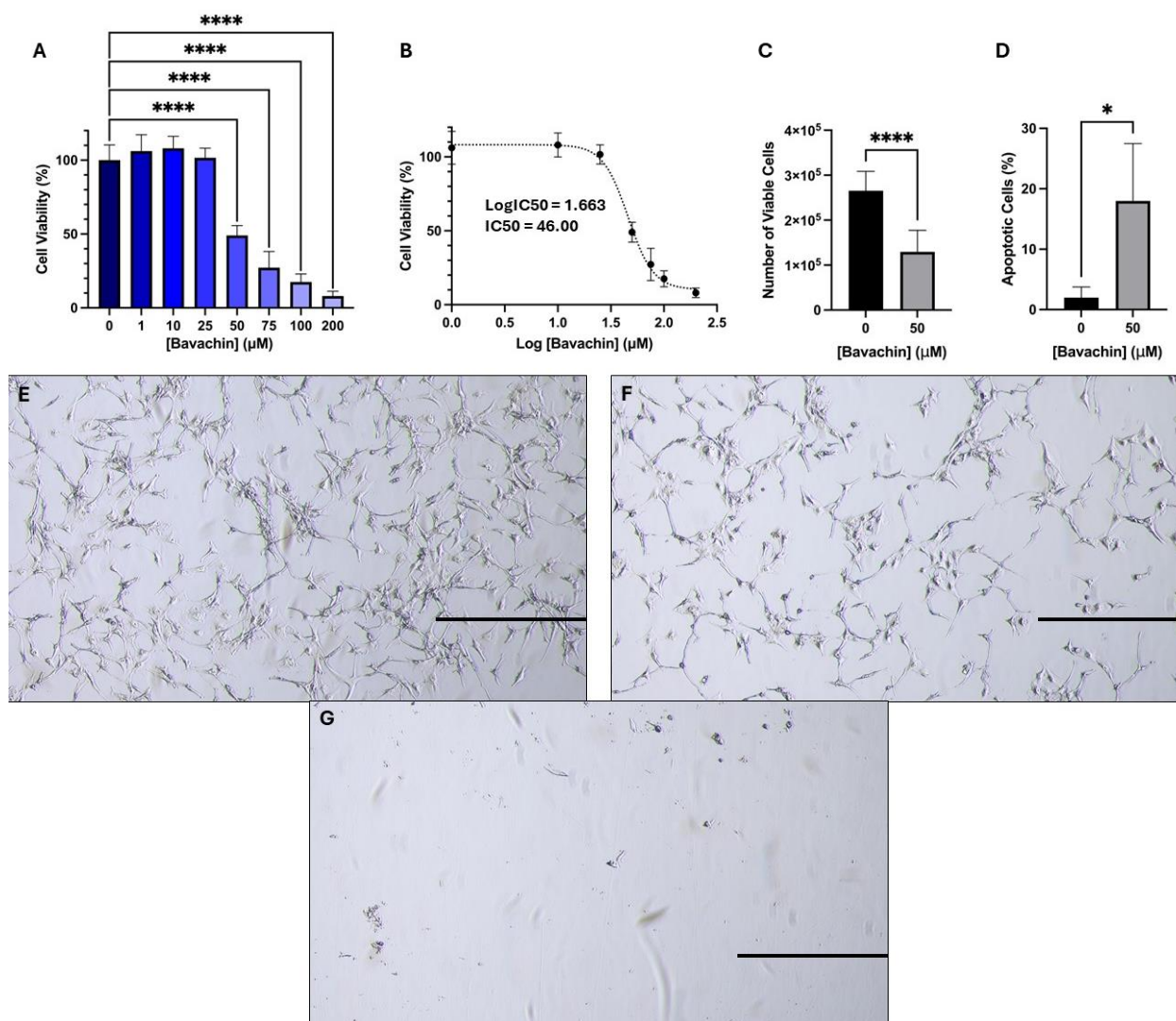


Figure 1. Cell viability after 48 hours of treatment with a range of bavachin concentrations. A. SRB staining following bavachin treatment in U-87 MG cells. B. Determination of the IC₅₀ value from SRB assays. C. Trypan blue assay was conducted to determine the number of viable cells following bavachin treatment. D. Proportion of apoptotic cells determined from trypan blue assay. E-G. Phase contrast microscopy after bavachin treatment (0 µM (E), 50 µM (F), and 200 µM (G)). Scale bar = 0.5 mm. All images were taken at 40X total magnification.

Bavachin Inhibits the Growth of U-87 MG Stem Cells

Stem cells are a subset of cells within malignant neoplasms that drive tumor growth.¹⁹ Tumorspheres, which are heterogeneous aggregates, typically contain hypoxic regions and cancer stem cells.²⁰ Compared to 2D cultures, 3D cell culture more effectively simulates the *in vivo* environment, as it allows for crucial cell-cell interactions and biological processes.²¹ As a result, 3D cell culture is increasingly used in preclinical trials to more accurately assess therapeutic effects.²¹ There was a significant reduction in tumorsphere volume after treatment with 50 µM and 100 µM of bavachin. Images of tumorspheres and the volume comparisons can be seen in **Figure 2**. **Figure 2A** and **Figure 2B** show no significant changes to tumorsphere size after treatment with 0 µM and 25 µM bavachin. **Figure 2C** and **Figure 2D** show tumorspheres of decreased volume after treatment with 50 µM and 100 µM bavachin, respectively. **Figure 2E** summarizes tumorsphere volume after treatment with different concentrations of bavachin and shows a significant decrease in tumorsphere volume in a concentration-dependent manner starting at 50 µM bavachin.

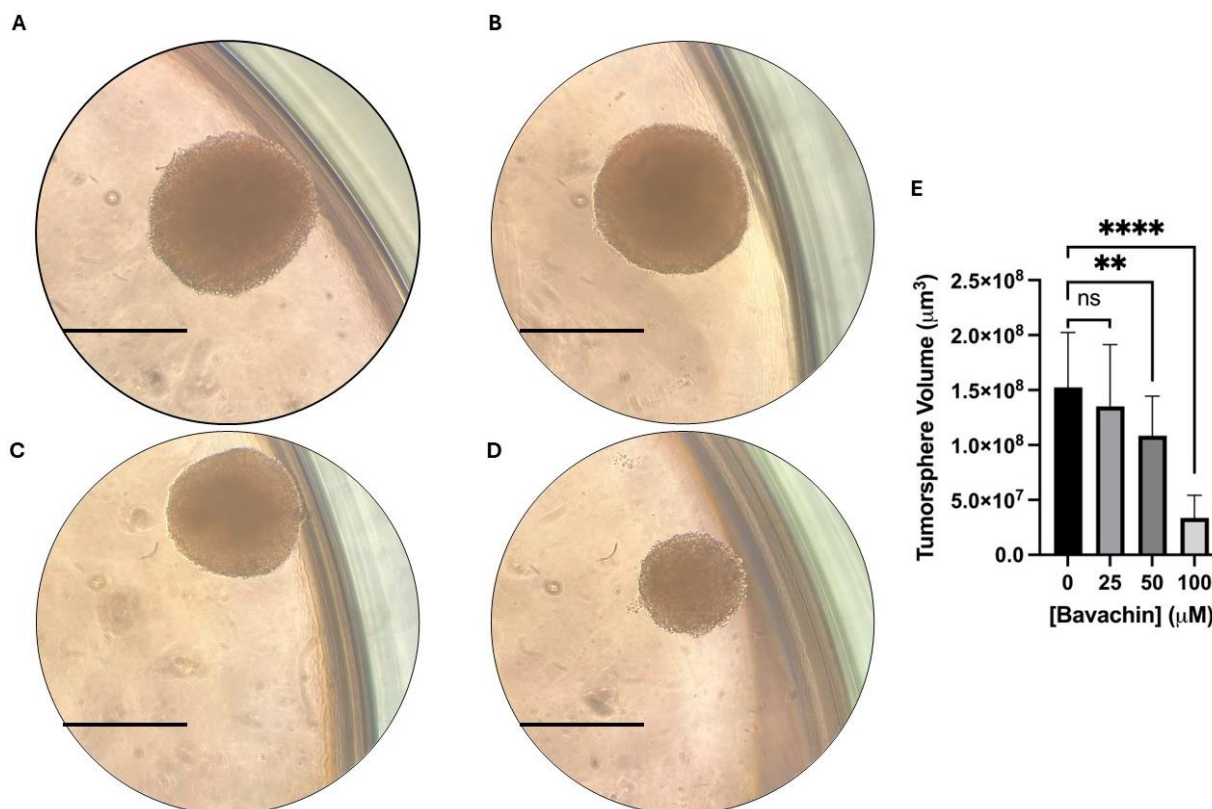


Figure 2. Bavachin inhibits U-87 MG stem cell growth. Images of tumorspheres after treatment with 0 μM (A), 25 μM (B), 50 μM (C), and 100 μM (D) of bavachin. All images were taken at 100X total magnification. Scale bar = 0.5 mm. Final tumorsphere volume was calculated for each treatment group (E).

Bavachin Exhibits Concentration-Dependent Interactions with Temozolomide

Bavachin and paclitaxel have reported to be synergistic in placental choriocarcinoma cells;¹⁵ therefore, we were encouraged to test the effects of bavachin in combination with TMZ. A second set of SRB assays was performed using different combinations of bavachin and TMZ ranging from 10-50 μM bavachin and 500-1000 μM TMZ. **Figure 3A** shows cell viability after treatment with bavachin, TMZ, or a combination. Combination treatments using 50 μM bavachin with various concentrations of TMZ showed the largest decrease in cell viability. As seen in **Figure 3B**, combination treatments show an additive effect at 10 and 25 μM bavachin with TMZ, as well as 50 μM bavachin with 500 μM TMZ. An additive effect indicates that the combination of the two drugs is equal to the sum effects of the drugs administered independently. Seven out of the nine combinations of bavachin and TMZ tested demonstrated drug additivity. Interestingly, the combination of 50 μM bavachin and 750 μM TMZ exhibited drug antagonism, in which the combined effect fell in-between what was observed from the individual drug responses. The combination of 50 μM bavachin and 1000 μM TMZ exhibited significant drug synergy, in which the combined effect was greater than the sum of the individual effects.

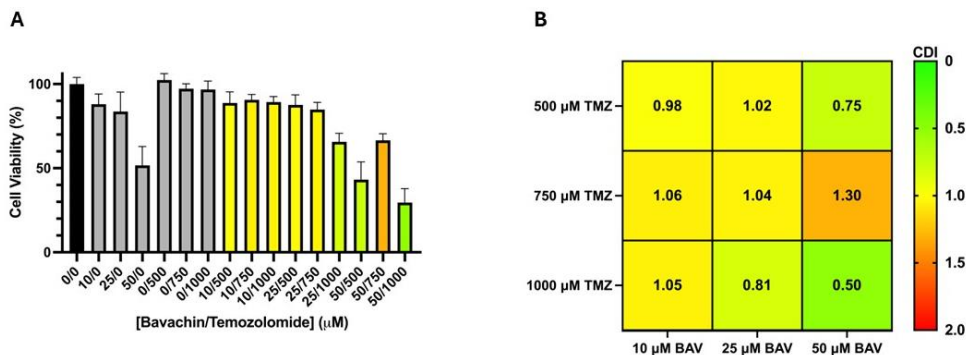


Figure 3. Cell viability after treatment with different concentrations of temozolomide, bavachin, or a combination. A. SRB assays were conducted to measure cell viabilities following 48 hours of the indicated treatment. B. Coefficient of drug interaction (CDI) values were calculated to determine drug additivity and synergy.

Bavachin Potentially Binds to Ornithine Decarboxylase to Inhibit U-87 MG Cell Growth

Although there have been several published findings on the effects of bavachin in cancer cells, ^{6, 15–18} a definitive binding target for bavachin has not yet been identified. We used ZINC20, CB-Dock2, and ChimeraX to determine and model the binding target of bavachin. **Figure 4A** shows a list of potential targets for bavachin from CB-Dock2. Human ornithine decarboxylase (ODC) was one of the most confident targets predicted by CB-Dock2 (p value = 1.558 X 10⁻³⁹). Since ODC expression has been implicated in glioblastomas,²⁸ we continued our analysis on ODC. Using the vina scores generated by CB-Dock2, it was determined that the best pocket for bavachin to bind on ODC is the C1 pocket. As seen in **Figure 4B**, the C1 pocket had the lowest Vina score of -9.2. The *in silico* model of bavachin and ODC using ChimeraX is shown in **Figure 4C**, and the predicted amino acid side chains of ODC that bind bavachin are identified in **Table 1**.

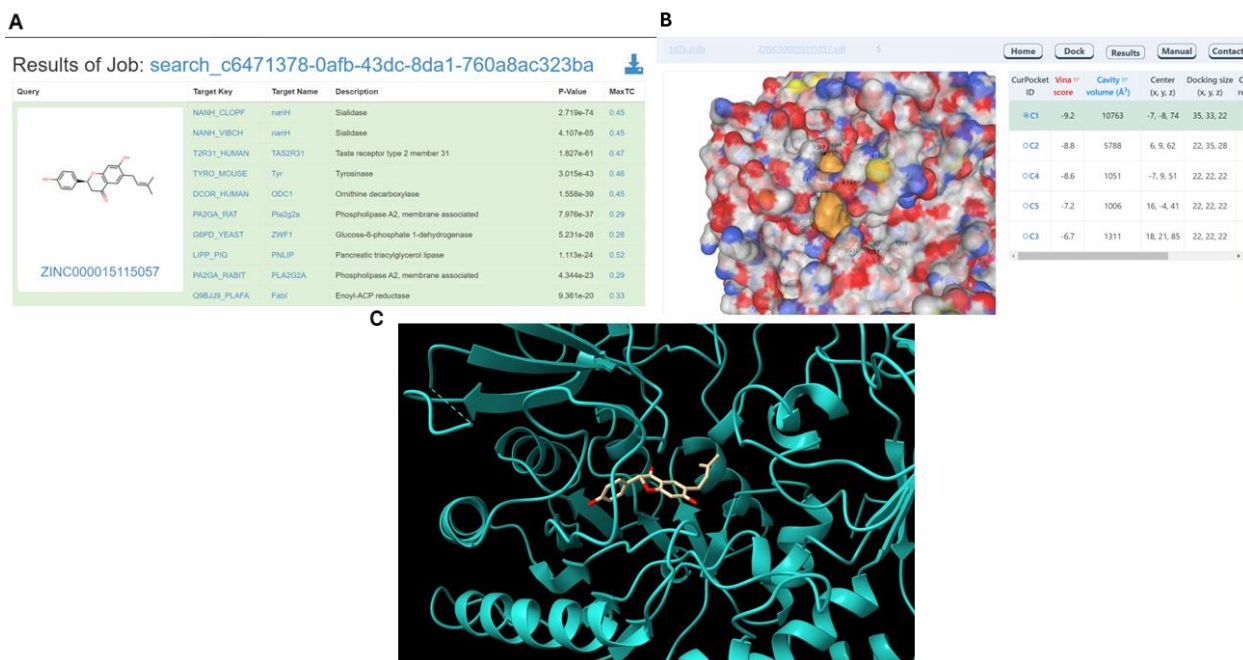


Figure 4. Bavachin potentially binds to ornithine decarboxylase. A. List of bavachin targets from CB-Dock2. B. Table of binding information for ODC from CB-Dock2. C. Image of bavachin (beige) binding to ODC (cyan) from ChimeraX.

Table 1. Predicted ornithine decarboxylase side chains in contact with bavachin. CB-Dock2 identified multiple amino acid residues in both chains of ODC that may bind bavachin. Highlighted residues are necessary for binding ornithine.²⁹

Chain A	Chain B
TYR323 CYS360 ASP361 GLY362 LEU363 THR396 PHE397 ASN398 GLY399 GLN401	ALA67 VAL68 CYS70 ASP72 ASP88 CYS89 ALA90 THR93 GLU94 GLN96 LEU97 SER100 ARG154 ALA156 THR157 ASP158 ASP159 SER160 LYS161 ALA162 VAL168 LYS169 PHE170 HIS197 VAL198 GLY199 SER200 GLY201 GLY237 GLU274 GLY276 ARG277 TYR331 ASP332 HIS333 TYR389

DISCUSSION

Glioblastoma, a highly invasive brain tumor, often proves fatal despite surgical and chemotherapeutic interventions.³⁰ Temozolomide (TMZ), a common chemotherapy agent for glioblastoma (GBM), encounters resistance in GBM cells through anti-apoptotic, DNA repair, and drug efflux mechanisms.^{3,4} This study aimed to evaluate the effects of bavachin, a natural compound known for inducing apoptosis in various cancer cells, in U-87 MG cells. Previous studies have shown that bavachin induces apoptosis by activating caspase-3 and caspase-9⁶ and by reducing mitochondrial membrane potential.¹⁵ Additionally, bavachin-induced apoptosis was associated with ER stress and the mitochondrial injury pathway (ROS/Mfn2/Akt) in HepG2 cells.⁶ However, it is unknown if bavachin induces apoptosis in GBM cells via similar mechanisms.

After we determined an IC₅₀ value of 46.00 μM for bavachin in U-87 MG cells, we proceeded with another assay designed to assess the apoptotic-inducing properties of bavachin: the trypan blue assay. Like the SRB assay, the trypan blue assay is used to determine cell viability. Our study provided evidence of bavachin's ability to induce apoptosis in GBM cells, with efficacy observed at 50 μM and higher concentrations. This study provided evidence that bavachin suppresses tumorsphere growth. These results are supported by a study in which bavachin suppressed placental choriocarcinoma tumorsphere growth.¹⁵ However, the apparent IC₅₀ of bavachin in our assay appeared higher than the IC₅₀ of 46.00 μM calculated from the SRB assay. This finding

may reflect the challenges small molecules face in penetrating three-dimensional tumorspheres and equally affecting cell growth in a more heterogeneous cancer cell population.³¹

When used in combination, drugs can exhibit synergy, in which the effect of the drugs in combination is greater than the effect of either drug independently. Synergistic interactions are important in cancer treatment to enhance the effects of the treatment while reducing the adverse effects.³² This is the reason many cancer patients are given “drug cocktails”. This study revealed several combinations of bavachin and TMZ that resulted in drug additivity. While the combination of 50 μM bavachin and 750 μM TMZ resulted in drug antagonism, co-administration of 50 μM bavachin significantly enhanced the effects of TMZ at 1000 μM , indicating that bavachin may enhance the therapeutic efficacy of TMZ at these concentrations. These observed drug interaction patterns between bavachin and TMZ likely reflect their complex interactions *in vitro*. TMZ is an alkylating agent,³ while we hypothesize bavachin inhibits ornithine decarboxylase (ODC) to reduce intracellular polyamine concentrations. At high (50/1000 μM) concentrations of both drugs, the combination may have overwhelmed the cells’ DNA repair mechanisms; DNA damage from TMZ may have synergized with polyamine depletion caused by ODC inhibition, which has been shown to destabilize the double helix, leading to enhanced cell death.³³ However, at an intermediate concentration of TMZ (750 μM) and a high concentration of bavachin (50 μM), antagonism may have occurred because ODC inhibition still reduced polyamine levels, slowing cell proliferation. Since TMZ is most effective in rapidly dividing cells, its cytotoxic potential may be diminished under these conditions.³⁴ While the combination of bavachin and TMZ was assessed in an SRB assay, this combination was not tested in the tumorsphere assay. Future studies could expand upon these findings by investigating the potential synergistic effects of bavachin and TMZ in a more complex tumorsphere environment.

Molecular docking can be used to aid in drug discovery and development. Docking allows researchers to compare the binding of drugs to targets by creating *in silico* models. This study found that ODC is a potential target for bavachin. ODC represents an attractive target in GBM, as ODC activity is positively correlated with GBM pathology and negatively correlated with progression-free survival in GBM patients.²⁸ ODC is the first enzyme involved in polyamine synthesis.³⁵ Polyamines, including putrescine, spermidine, and spermine, are present in mammalian cells in millimolar concentrations. Polyamines are involved in cell growth by maintaining protein and nucleic acid synthesis, stabilizing chromatin structure, regulating apoptosis, and offering protection from oxidative damage. Polyamine metabolism is dysregulated in cancer indicating that increased levels of polyamines are necessary for cancer development and progression.³⁶ Glioblastoma multiforme is characterized by tumor-associated myeloid cells (TAMCs). ODC and polyamines were found to be upregulated in TAMCs.³⁷ We predict bavachin may inhibit ODC based on the binding score of ODC to bavachin and the involvement of ODC and polyamines in glioblastoma. Excitingly, bavachin is predicted to bind to ODC in the same active site as ornithine.²⁸ Inhibiting ODC in cancer cells would likely inhibit cancer growth and DNA repair.³² Taken together, we can identify bavachin as a promising drug candidate for inhibiting GBM cell and tumorsphere growth.

CONCLUSIONS

In summary, our hypothesis was supported as bavachin reduced glioblastoma multiform cancer cell viability, induced apoptosis, inhibited tumorsphere growth, and enhanced temozolomide efficacy. Molecular docking analysis allowed us to identify ornithine decarboxylase as a possible target of bavachin, which should be evaluated *in vitro* in future studies.

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PRESS SUMMARY

Glioblastoma multiforme is one of the most aggressive forms of cancer with few effective treatments. The current first-line treatment temozolomide results in harmful side effects and tumor recurrence. Bavachin is a flavonoid that has been tested in multiple cancer cell lines including oral, bone, multiple myeloma, choriocarcinoma, colorectal, and liver cancer but not glioblastoma. This study determined that bavachin is effective at killing glioblastoma cells and can enhance the effects of temozolomide.

On the Center of Mass of the Half n -Ball

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ABSTRACT

This project explores how the center of mass (COM) of a half n -ball depends on the dimension, n . We study the case of uniform density, where the COM is equivalent to the object's centroid, or geometric center. We find a closed form solution, a sequence describing the centroid in n dimensions, which confirms the common two and three dimensional cases. Furthermore, the sequence is analytically proven to converge to zero in the limit as n approaches infinity.

KEYWORDS

Mechanics; Mathematical Physics; Center of Mass; Centroid; Hyper-Geometry

INTRODUCTION

When first learning mechanics we often begin by studying the motion of a point object. In general, determining the motion of an extended object is more involved since they are essentially the collection of many individual point masses. The way we can simplify these calculations is by treating the object as if all its mass were at a single point, its center of mass (COM). As one would expect, the COM of the object depends not only on the shape of the object, but also the mass distribution. For example, the COM of a ball with uniform density will be different than the COM of a ball that has one hemisphere with a higher density than the other.

Since we can learn so much about the motion of a system by studying its COM, it is a common tool in many fields of physics. For example, in many cases when studying orbital dynamics it is sufficient to consider the motion of the centers of mass of the orbiting bodies. We find the COM used in many engineering applications as well. Specifically, it is a great tool in designing buildings to be stable to seismic perturbation. By designing counterweights and balancing systems, it is possible to create systems which restore a building's position given a perturbation to its foundation.¹ A particularly interesting application of the COM comes from the field of biomechanics. One of the most common models of balance is called the 'inverted pendulum model' in which the leg is approximated as a point mass situated above the foot and connected by a rod.^{2,3} Moreover, the COM trajectory (in the sagittal plane) is of extreme importance when discussing the equilibrium of a person with prosthetics or humanoid robots, and such complex calculations are performed using neural networks.⁴ Furthermore, the calculations of the COM in n -dimensions is a good introduction for students interested in string theory or in mathematics.⁵

Mathematically, the COM, C of an arbitrary massive object O is given by

$$C = \frac{1}{M} \int_O \vec{r} dm,$$

where M is the total mass of the object, and \vec{r} is the vector pointing from the origin to the mass element dm .⁶ Notice that this is simply the mass-averaged position vector. For our purposes we consider only the case of a uniform density

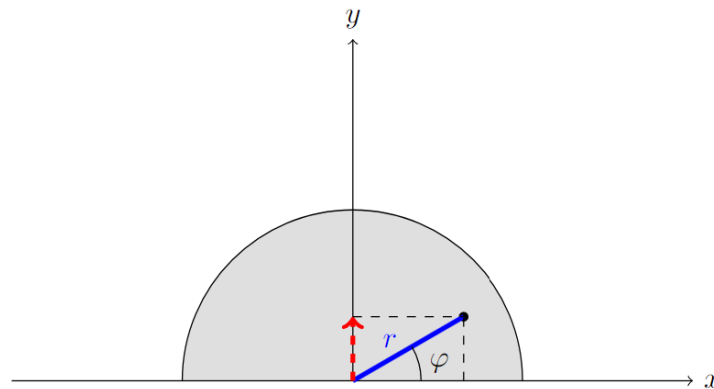


Figure 1. Figure representing the two dimensional case. The length, r , and the angle, φ , show an arbitrary position vector lying in the disk. The dashed, red vector represents the y -component which will be used for calculations.

distribution, in which case we can rewrite this integral in terms of volume by substituting $M = \rho V$, $dm = \rho dV$, where ρ is the density and V is the total volume of the object. Then the integral simplifies to the volume averaged position vector,

$$C = \frac{1}{V} \int_V \vec{r} dV \tag{Equation 1.}$$

Therefore, if the object has uniform density, then the COM is entirely equivalent to the geometric center of the object, or, its *centroid*.

Consider the following two examples, in which the COM of a half ball is found for two familiar cases: two and three dimensions (adapted from problems 3.21 and 3.22 from Taylor).⁶

Two Dimensional Case

In the 2D case we have a half disk of radius R and a uniform mass distribution. The base of the disk is situated along the x -axis with its center at the origin. A visualization of this system is shown as **Figure 1**. Due to the geometry of the disk, it is more appropriate to use polar coordinates, where,

$$\begin{aligned} x &= r \cos \varphi \\ y &= r \sin \varphi \\ dA &= r dr d\varphi. \end{aligned}$$

From the symmetry of the object we know that the COM must lie along the axis of symmetry, the y -axis. This allows us to simply replace \vec{r} (**Equation 1**) with the y -coordinate, $y = r \sin \varphi$. Thus,

$$C = \frac{1}{A} \int y dA = \frac{2}{\pi R^2} \int_0^\pi \int_0^R r^2 \sin \varphi dr d\varphi = \frac{4}{3\pi} R \approx 0.424R.$$

Notice that C represents only the y -component to the COM, however by our choice of coordinates the x -component is 0 so C sufficiently defines the entire COM vector.

Three Dimensional Case

In this case there is a half sphere of radius R and a uniform mass distribution. The base of the half sphere lies on the xy -plane with its center at the origin. This system is represented in **Figure 2**. Of course, it is best to use spherical coord-

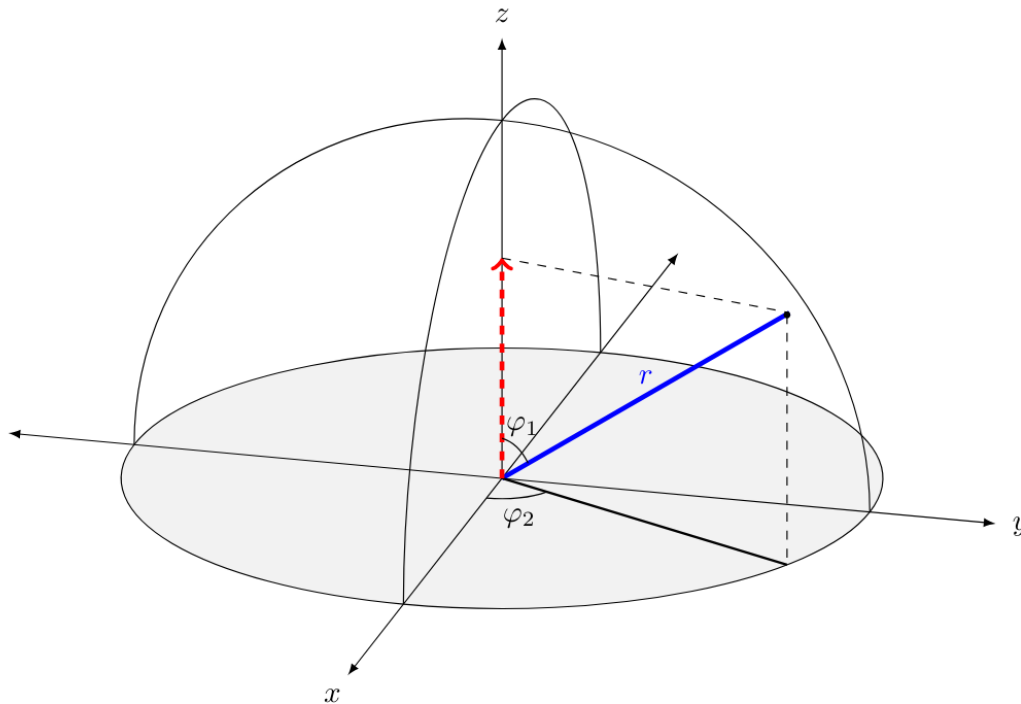


Figure 2. This figure represents 3-dimensional spherical coordinates, where φ_1 is measured from the positive z -axis and φ_2 is measured from the positive x -axis. Similarly to Figure 1, the dashed, red vector represents the component which we use to calculate the COM, in this case, the z -component.

dinates, where,

$$\begin{aligned}
 x &= r \sin \varphi_1 \cos \varphi_2 \\
 y &= r \sin \varphi_1 \sin \varphi_2 \\
 z &= r \cos \varphi_1 \\
 dV &= r^2 \sin \varphi_1 \, dr d\varphi_1 d\varphi_2.
 \end{aligned}$$

Similarly to the 2D case, symmetry dictates that the COM lies along the z -axis. Then,

$$C = \frac{1}{V} \int z \, dV = \frac{3}{2\pi R^3} \int_0^{\pi/2} \int_0^{2\pi} \int_0^R r^3 \cos \varphi_1 \sin \varphi_1 \, dr d\varphi_2 d\varphi_1 = \frac{3}{8}R = 0.375R.$$

Notice that similarly to the two dimensional case, the COM is a vector in 3-dimensional space, but since the z -component is the only non-zero component, C sufficiently describes the COM. This convention will be used for the general n -dimensional case as well.

If we compare the two and three dimensional cases we find that $C_2 = 0.424 > 0.375 = C_3$, or in words, when we moved up one dimension the COM became closer to the origin. This begs the question of what happens when we continue increasing the dimension. In this paper we look to answer the following two questions:

1. As the number of dimensions increases, does the COM continue moving closer to the origin?

2. If so, does the COM of the half n -ball converge to zero as intuition would predict?

In principle, we could examine the trend in higher dimensions by directly computing the fourth, fifth, and even higher dimensional cases individually. However, as we will see, we can analytically solve the problem without ever specifying the dimension n , and as in any problem in physics, generalizing the solution leads to deeper understanding. This theoretical exercise will not only yield the general solution, but it will give us insight into the pattern we see at lower dimensions. In the following sections we will address the above questions by constructing a closed form describing the COM in the arbitrary n -dimensional case. Since the domain of this function is the natural numbers, this solution is a sequence and so we may then use techniques from calculus and analysis to study the convergence of this sequence.

RESULTS

The n Dimensional Case

When we generalize the above examples to n -dimensions, we must work in n -dimensional spherical coordinates. The generalization is fairly obvious with Cartesian coordinates. Let $\{e_i \mid i \in I\}$ be a set of orthonormal vectors, where I is our indexing set. Then in n -dimensional space a vector \vec{x} can be written as $\vec{x} = \xi_1 e_1 + \xi_2 e_2 + \dots + \xi_n e_n$, where ξ_i is the component of \vec{x} in the e_i direction⁷. In spherical coordinates however, the vector \vec{x} can be expressed in terms of one radial component, r , and $n - 1$ angular coordinates as $\vec{x} = (r, \varphi_1, \varphi_2, \dots, \varphi_{n-1})$, where $r \geq 0$, $\varphi_j \in [0, \pi]$ for $j \in \{1, 2, \dots, n - 2\}$, and $\varphi_{n-1} \in [0, 2\pi)$. Just as in the lower dimensional cases, trigonometry can be used to change bases and convert from spherical to Cartesian coordinates. The conversion is given by **Equations 2, 3, 4, and 5** below,⁷

$$\xi_1 = r \cos \varphi_1 \tag{Equation 2.}$$

$$\xi_j = r \cos \varphi_j \prod_{k=1}^{j-1} \sin \varphi_k \quad (j = 2, \dots, n - 2) \tag{Equation 3.}$$

$$\xi_{n-1} = r \sin \varphi_{n-1} \prod_{k=1}^{n-2} \sin \varphi_k \tag{Equation 4.}$$

$$\xi_n = r \cos \varphi_{n-1} \prod_{k=1}^{n-2} \sin \varphi_k \tag{Equation 5.}$$

It may not be immediately clear where these change-of-basis equations come from, however understanding it is critical to determining the centroid of the half hyper-sphere. In two and three dimensions the axis of symmetry was obvious visually, however visual arguments no longer suffice when working in higher dimensional spaces. That being said, the three dimensional case can help give us *some* visual intuition. It is clear from the **Equations 2-5** above that φ_1 is the angle ranging from 0 to π , measured from the positive e_1 axis. Due to this, the $\cos \varphi_1$ term of ξ_1 shows that it is the projection of \vec{x} onto the e_1 axis. Similarly, φ_2 is orthogonal to φ_1 and is measured from the positive e_2 axis. This means that written out, $\xi_2 = r \sin \varphi_1 \cos \varphi_2$. In this case, the $\sin \varphi_1$ term projects \vec{x} onto the $n - 1$ dimensional subspace orthogonal to e_1 , and the $\cos \varphi_2$ term then projects it onto the e_2 axis. This process continues so that the ξ_j component is projection of \vec{x} onto the $n - (j - 1)$ dimensional subspace spanned by $\{e_j, e_{j+1}, \dots, e_{n-1}, e_n\}$, and then projected onto the e_j axis. This ends when we are left only with a two dimensional subspace spanned by $\{e_{n-1}, e_n\}$, with φ_{n-1} running from 0 to 2π measured from the positive e_n to the positive e_{n-1} axis. This explains why the only difference between ξ_{n-1} and ξ_n is the $\cos \varphi_{n-1}$ term on ξ_n and the $\sin \varphi_{n-1}$ term on ξ_{n-1} . For a concrete example, consider $n = 3$. Then, $(\xi_1, \xi_2, \xi_3) = (z, y, x)$, φ_2 is the angle running from the positive x -axis to the positive y -axis, and φ_1 is the angle from the positive z -axis to the xy -plane.

In order to calculate the centroid according to **Equation 1** above, we need the volume of an n -dimensional half ball,

V_n , and the n -dimensional spherical volume element, dV . From Blumenson,⁷

$$dV = r^{n-1} \prod_{k=1}^{n-2} \sin^k(\varphi_{n-1-k}) dr d\varphi_1 d\varphi_2 \dots d\varphi_{n-1}$$

$$dV = r^{n-1} dr \sin^{n-2}(\varphi_1) \sin^{n-3}(\varphi_2) \dots \sin(\varphi_{n-2}) d\varphi_1 d\varphi_2 \dots d\varphi_{n-1}$$
Equation 6.

Additionally, from Smith⁸ and Wang⁹ we have that the n -ball of radius R defined by the set

$$B_n = \{\mathbf{x} = (x_1, \dots, x_n) \mid x_1^2 + \dots + x_n^2 \leq R^2\}$$

has the volume

$$V(B_n) = \frac{2\pi^{n/2}}{n\Gamma(\frac{n}{2})} R^n,$$
Equation 7.

In the formula, $\Gamma(n/2)$ represents Euler’s gamma function evaluated at $n/2$.

We can simplify **Equation 7** using some gamma function identities. The gamma function is Euler’s extension of the factorial function to non integer arguments. As such, it satisfies some properties that match the behavior of factorial function. For example,¹⁰ for any $x > 0$,

$$x\Gamma(x) = \Gamma(x + 1),$$
Equation 8.

and in particular, if n is a natural number then,

$$\Gamma(n + 1) = n!$$
Equation 9.

just as we would expect. The two properties shown by **Equations 8** and **9** above can be used to show that for the case of even n ,

$$\Gamma\left(\frac{n}{2}\right) = \left(\frac{n}{2} - 1\right)!$$
Equation 10.

In the case that n is odd,

$$\Gamma\left(\frac{n}{2}\right) = \frac{\pi^{\frac{1}{2}}(n - 2)!!}{2^{\frac{(n-1)}{2}}}$$
Equation 11.

Equation 10 is a direct result of **Equation 9**, and **Equation 11** can be proven easily via induction. Now that we have closed form solutions for the gamma function evaluated at integer and half integer arguments, we can plug into **Equation 7** and divide by two to get the volume of the *half* n ball. Since $\Gamma(\frac{n}{2})$ depends on the parity of n , then the volume of the half n ball, which we denote by V_n , is given by the following piecewise formula,

$$V_n = \begin{cases} \frac{\pi^{n/2}}{n(\frac{n}{2}-1)!} R^n & \text{for even } n \\ \frac{(2\pi)^{\lfloor (n-1)/2 \rfloor}}{(n)!!} R^n & \text{for odd } n \end{cases}$$
Equation 12.

Now that we are equipped with the adequate tools, we are finally prepared to solve **Equation 1** in the arbitrary n -dimensional case. Recall **Equation 1**

$$C = \frac{1}{V} \int_V \vec{r} dV.$$

For the half n -ball, this integral turns into,

$$C = \frac{1}{V_n} \int_{V_n} \vec{r} r^{n-1} \prod_{k=0}^{n-2} \sin^k(\varphi_{n-1-k}) d\varphi_{n-1-k}.$$
Equation 13.

Recall from the two and three dimensional cases that if a convenient choice of axes is chosen, we can force the axis of symmetry to lie along one of the Cartesian unit vectors. In other words, if we align the axis of symmetry with one

of the bases of the Cartesian coordinate system, say e_k , then \vec{r} can be replaced with ξ_k . Recall that for n -dimensional spherical coordinates, angular components φ_1 through φ_{n-2} run from 0 to π , and φ_{n-1} runs from 0 to 2π . To create a half ball we simply restrict the domain of one of the angles. For the sake of simplicity, let φ_1 run only from 0 to $\pi/2$, thus making ξ_1 the component which lies along the axis of symmetry. This turns **Equation 13** into,

$$\begin{aligned}
 C &= \frac{1}{V_n} \int_{V_n} r \cos(\varphi_1) r^{n-1} \prod_{k=0}^{n-2} \sin^k(\varphi_{n-1-k}) d\varphi_{n-1-k} \\
 &= \frac{1}{V_n} \int_0^R r^n dr \int_0^{\pi/2} \cos(\varphi_1) \sin^{n-2}(\varphi_1) d\varphi_1 \\
 &\quad \int_0^\pi \dots \int_0^\pi \prod_{k=1}^{n-3} \sin^k(\varphi_{n-1-k}) d\varphi_{n-1-k} \int_0^{2\pi} d\varphi_{n-1},
 \end{aligned}
 \tag{Equation 14}$$

For $n > 1$, integrating by parts gives us that

$$\int_0^{\pi/2} \cos(\varphi_1) \sin^{n-2}(\varphi_1) d\varphi_1 = \frac{1}{n-1}
 \tag{Equation 15}$$

By using **Equation 15** and integrating the radial and φ_{n-1} terms, we simplify **Equation 14** to the following,

$$C = \frac{2\pi R^{n+1}}{(n+1)V_n} \frac{1}{n-1} \int_0^\pi \dots \int_0^\pi \prod_{k=1}^{n-3} \sin^k(\varphi_{n-1-k}) d\varphi_{n-1-k}
 \tag{Equation 16}$$

Now all that remains is to solve the multiple integral at the end of **Equation 14**. Notice that for any k , $\sin^k(\varphi_{n-1-k})$ is a function of only one variable, and so we may use Fubini's theorem to split this multiple-integral of a product into a product of single integrals, or,

$$\int_0^\pi \dots \int_0^\pi \prod_{k=1}^{n-3} \sin^k(\varphi_{n-1-k}) d\varphi_{n-1-k} = \prod_{k=1}^{n-3} \int_0^\pi \sin^k(\varphi_{n-1-k}) d\varphi_{n-1-k}
 \tag{Equation 17}$$

Now, using the power reduction formula we find,

$$\begin{aligned}
 \int_0^\pi \sin^n(x) dx &= -\frac{1}{n} \sin^{n-1}(x) \cos(x) \Big|_0^\pi + \frac{n-1}{n} \int_0^\pi \sin^{n-2}(x) dx \\
 &= \frac{n-1}{n} \int_0^\pi \sin^{n-2}(x) dx.
 \end{aligned}
 \tag{Equation 18}$$

Thus, as a result of our bounds, we have a recursive relation describing the solution to the integral. This recursion relation can be repeatedly applied to attain closed form solutions to **Equation 18**. If n is even then,

$$\int_0^\pi \sin^n(x) dx = \left(\frac{n-1}{n}\right) \left(\frac{n-3}{n-2}\right) \dots \left(\frac{3}{4}\right) \int_0^\pi \sin^2(x) dx = \frac{(n-1)!!}{n!!} \pi,
 \tag{Equation 19}$$

and if n is odd then,

$$\int_0^\pi \sin^n(x) dx = \left(\frac{n-1}{n}\right) \left(\frac{n-3}{n-2}\right) \dots \left(\frac{2}{3}\right) \int_0^\pi \sin(x) dx = \frac{(n-1)!!}{n!!} 2.
 \tag{Equation 20}$$

More concisely, we have,

$$\int_0^\pi \sin^n(x) dx = \begin{cases} \frac{\pi(n-1)!!}{n!!} & \text{for even } n \\ \frac{2(n-1)!!}{n!!} & \text{for odd } n \end{cases}
 \tag{Equation 21}$$

We can now use the above equation to simplify **Equation 17**. From **Equation 21** we see that the only difference between the odd and the even case is whether the integral carries a factor of 2 or a factor of π . Consequently, when we take the product of these integrals it is important to count how many odd terms and how many even terms are in each product. Notice that if n is even, then $n - 3$ is odd, which means that the product has $\frac{n-4}{2} + 1$ terms with k odd, and $\frac{n-4}{2}$ terms with k even. Similarly, in the case that n is odd, then $n - 3$ is even, meaning there are $\frac{n-3}{2}$ terms with k even and $\frac{n-3}{2}$ terms with k odd. Therefore, putting this all together we have that,

$$\prod_{k=1}^{n-3} \int_0^\pi \sin^n(x) dx = \begin{cases} 2^{(n-4)/2+1} \pi^{(n-4)/2} \left[\frac{(n-4)!!}{(n-3)!!} \frac{(n-5)!!}{(n-4)!!} \cdots \frac{(2)!!}{(3)!!} \frac{(0)!!}{(1)!!} \right] & \text{for even } n \\ 2^{(n-3)/2} \pi^{(n-3)/2} \left[\frac{(n-4)!!}{(n-3)!!} \frac{(n-5)!!}{(n-4)!!} \cdots \frac{(1)!!}{(2)!!} \frac{(0)!!}{(1)!!} \right] & \text{for odd } n \end{cases}$$

which is a telescoping product which simplifies nicely as,

$$\prod_{k=1}^{n-3} \int_0^\pi \sin^n(x) dx = \begin{cases} 2(2\pi)^{(n-4)/2} \frac{1}{(n-3)!!} & \text{for even } n \\ (2\pi)^{(n-3)/2} \frac{1}{(n-3)!!} & \text{for odd } n \end{cases} \tag{Equation 22.}$$

Putting together **Equations 12, 16, and 22**, we get that for even n

$$C = \frac{2\pi R^{n+1} n(\frac{n}{2} - 1)!}{(n + 1)\pi^{n/2} R^n} \left(\frac{1}{n - 1} \right) \left(2(2\pi)^{(n-4)/2} \frac{1}{(n - 3)!!} \right) = \frac{2^{n/2} n(\frac{n}{2} - 1)!}{\pi (n + 1)!!} R, \tag{Equation 23.}$$

and if n is odd, we find that,

$$C = \frac{2\pi R^{n+1} (n)!!}{(n + 1)(2\pi)^{[(n-1)/2]} R^n} \left(\frac{1}{n - 1} \right) \left((2\pi)^{(n-3)/2} \frac{1}{(n - 3)!!} \right) = \frac{n!!}{(n + 1)!!} R \tag{Equation 24.}$$

Thus, the centroid of an n -dimensional half ball of radius R can be described with the following (*piecewise*) sequence which depends only on the parity of n ,

$$C_n = \begin{cases} \frac{2^{n/2} n(\frac{n}{2} - 1)!}{\pi (n + 1)!!} R & \text{for even } n \\ \frac{n!!}{(n + 1)!!} R & \text{for odd } n \end{cases} \tag{Equation 25.}$$

Notice that since the centroid is a function of n we now add the subscript to C_n to specify the dimension. Overall this is a very interesting result but there are some questions which remain. For example notice that the value of C_n is much more concise for odd values of n than for even values of n . This suggests that there may be a more elegant way to express C_n for even n . If it exists, what is this expression? Additionally, one of the benefits of having a closed form expression for C_n as a function of n is that we may now test the global properties of the sequence. Specifically, does the sequence converge? If so, what does it converge to? The following sections work to find an alternate expression for the even subsequence and to test C_n in general for convergence.

Simplifying the Even Case

Let G_n be the even subsequence (C_n for even n). Then for all even integers $n > 0$, G_n is defined by **Equation 26**,

$$G_n = \frac{2^{n/2} n(\frac{n}{2} - 1)!}{\pi (n + 1)!!} \tag{Equation 26.}$$

Consider the value of G_{n+2} . By definition we have,

$$G_{n+2} = \frac{2^{\frac{n}{2}+1}(n+2)\left(\frac{n}{2}\right)!}{\pi(n+3)!!}$$

$$G_{n+2} = \frac{2 * 2^{n/2}(n+2)\frac{n}{2}\left(\frac{n}{2}-1\right)!}{\pi(n+3)(n+1)!!}$$

$$G_{n+2} = \frac{n+2}{n+3} \frac{2^{n/2}n\left(\frac{n}{2}-1\right)!}{\pi(n+1)!!}$$

$$G_{n+2} = G_n \frac{n+2}{n+3}$$

Thus, there is a recursive relation describing G_n . Just as we did before in determining the value of $\int_0^\pi \sin^n(x) dx$, we can repeatedly apply the recursive relation to relate G_n to the base case G_2 which has a known numerical value, meaning we once again have a closed form expression for G_n . In general, for any even positive integer n ,

$$G_n = \frac{2}{\pi} \frac{n!!}{(n+1)!!} \tag{Equation 27.}$$

Therefore, we can express the even sequence in a much more elegant way, matching the form of the odd sequence. This gives us the revised definition for C_n ,

$$C_n = \begin{cases} \frac{2}{\pi} \frac{n!!}{(n+1)!!} R & \text{for even } n \\ \frac{n!!}{(n+1)!!} R & \text{for odd } n \end{cases} \tag{Equation 28.}$$

This alternative form of expressing the even sequence makes proving that C_n converges a much simpler task. Since the even and odd sequence only differ by a numerical factor, if we can show that the odd sequence $\frac{n!!}{(n+1)!!}$ is convergent then proving that the even sequence converges is trivial.

The Convergence of C_n

In this section we discuss the convergence of our sequence, C_n . Note that since C_n is a monotonic, decreasing sequence, bounded below by zero, then it must be that C_n converges to *something*. Then proving convergence alone is not too difficult of a problem. The true goal of this section is to show, specifically, that C_n converges to zero. Then let $U_n = \frac{n!!}{(n+1)!!}$ be the subsequence of C_n for all odd n .

Proposition 1. U_n converges to zero as n goes to infinity.

Proof. By definition, $\lim_{n \rightarrow \infty} U_n = 0$ if for any $\varepsilon > 0$ there exists some $N \in \mathbb{N}$ such that for all $n \geq N$,

$$\left| \frac{n!!}{(n+1)!!} \right| < \varepsilon.$$

Since U_n is positive for all n then this requirement is the same as

$$\frac{n!!}{(n+1)!!} < \varepsilon,$$

or

$$\frac{(n+1)!!}{n!!} > \frac{1}{\varepsilon}.$$

In words, since U_n is always positive, to show that it converges to zero is equivalent to showing that the inverse is not bounded above.

Let $a_n = \frac{1}{U_n} = \frac{(n+1)!!}{n!!}$ be a sequence defined for positive odd integers, n . We can express this using product notation as follows,

$$a_n = \prod_{k=0}^{\frac{n-1}{2}} \frac{2k+2}{2k+1}.$$

With some algebra we find,

$$\begin{aligned} a_n &= \prod_{k=0}^{\frac{n-1}{2}} \frac{2k+2}{2k+1} \\ &= \prod_{k=0}^{\frac{n-1}{2}} \left(1 + \frac{2k+2}{2k+1} - 1 \right) \\ &= \prod_{k=0}^{\frac{n-1}{2}} \left(1 + \frac{1}{2k+1} \right) \end{aligned}$$

By Theorem 3 of Section 28 in Knopp,¹¹ we know that in the limit as $n \rightarrow \infty$, a_n converges if and only if $\lim_{n \rightarrow \infty} \sum_{k=0}^{\frac{n-1}{2}} \frac{1}{2k+1}$ converges. By the integral test, the series $\sum_{k=0}^{\frac{n-1}{2}} \frac{1}{2k+1}$ is clearly divergent and so a_n must be divergent as well. Therefore, since a_n is not bounded above, then U_n converges to zero as $n \rightarrow \infty$. QED

The above proof only deals with the the odd sequence, U_n , however since G_n has the same form, the same process shows that G_n converges to zero as well. Therefore, we have shown that as $n \rightarrow \infty$, $C_n \rightarrow 0$.

DISCUSSION

This result leads to many interesting points. First, notice that due to the symmetry, the centroid of the n -ball is simply the origin regardless of the dimension. Then from the previous sections we see that as the dimension increases, the centroid of the half n -ball approaches the centroid of the n -ball. In other words, the higher the dimension of the n -ball, the more the mass becomes concentrated near the origin.

The case of the half n -ball is quite interesting, yet it leads to some natural following questions. In this project we focus solely on the case of uniform density, meaning the mass integral can be changed to a volume integral. It is interesting to consider what would happen to the centroid if the density depended on the radius rather than staying constant. Suppose the density took the form $\rho(r) = r^k$, where k is an integer. If k is negative then the mass concentration increases as you approach the origin and we expect that the COM would converge to zero at a faster rate. However if $k > 1$ it could lead to some interesting cases. For example, for $k \gg 1$, you can approximate the ball as if all the mass is distributed throughout the surface, and rather than dealing with the n ball we would be dealing with its outer shell. Additionally, is there some sort of critical mass distribution for which C_n does not converge as $n \rightarrow \infty$? Furthermore, all these questions deal with spherical geometries. What sort of trends are present when we consider the higher dimensional analogs of other shapes? Do we still expect their COMs to converge to the origin in higher dimensions. Consider the hypercube. Regardless of the dimension, the distance from the hyper cube’s COM to the origin is the same. Could there be some shape for which the COM moves farther from the origin as we increase the dimension? Clearly, many related questions remain, and in the future it would be interesting to explore these alternative density distributions and geometries.

CONCLUSIONS

This project worked to generalize the problem of the COM of the half disk (2D) and half ball (3D) to the arbitrary n -dimensional case with the goal of both generalizing our 2D and 3D solutions as well as gaining more understanding as to why we see the trend we do at lower ($n \leq 3$) dimensions. In order to solve the problem in n dimensions we leveraged the

spherical symmetry of the system just as in the lower dimensional cases. First, we chose the basis so that the axis of symmetry lies along only one of the Cartesian axes. This allowed us to describe the COM vector using only one component which simplifies calculations substantially. After choosing the correct coordinate system, solving the integral was possible with a few intermediate steps. As a result we derived a function for the COM which depends purely on the number of dimensions n . By finding a closed form function describing the centroid of the half n -ball, not only do we construct a more general solution but we also are now able to test the global properties of the function as we vary n . The ability to explore trends in an *analytic* way gives us a much deeper insight to the problem. In particular, we show that $\lim_{n \rightarrow \infty} C_n = 0$.

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PRESS SUMMARY

This project explores the center of mass (COM) of a certain class of objects in different dimensions. The COM is an important property in physics used to determine the motion of objects as it drastically simplifies calculations. In particular, we study the half n -dimensional ball, for example the half disk ($n = 2$), half ball ($n = 3$), and their higher ($n > 3$) dimensional analogues. In our study, we let the density of the object be constant throughout so that the COM is the same as

the physical center of the object, known as the centroid. Rather than performing manual computations for each individual case we find a formula describing the centroid in any dimension. Furthermore, we analyze the trend as the number of dimensions increases. We show that as the number of dimensions increases infinitely, the centroid of the *half* n -ball gets arbitrarily close to centroid of the *full* n -ball.

