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The joint effect of multiple health behaviors on odds of diabetes, depression

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ABSTRACT

This study examines the relationship between health determinant behaviors themselves, and their subsequent combined relationship with chronic illness (diabetes/impaired glucose regulation, depression). While numerous studies have proven the benefits of engaging in more healthy behaviors, the question has not been answered whether the effect of multiple healthy behaviors together is greater than the sum of the effects alone.

The study design is cross-sectional, using data on the adult population from the 2017 California Health Interview Survey (CHIS).[1] A total of 21,116 participants were included in final analyses. We used multivariable adjusted logistic regression to calculate odds ratios for diabetes and for depression at each subsequent level of a healthy lifestyle index (HLI). We also calculated the adjusted odds ratios between adjacent levels of the index.

The odds of having depression and, separately, of having diabetes each decreased with each additional healthy lifestyle behavior, with three of five depression ratios significant at $p < 0.05$, and four of five significant for diabetes. The magnitude of the association between the HLI level and odds for disease declines exponentially with each additional healthy lifestyle factor, contrary to the hypothesis, for depression, but fits the hypothesis for diabetes. Our results are important for health promotion, suggesting that even one healthy behavior may dramatically decrease the odds for having depression, regardless of the type of healthy behavior chosen. Our results also show an association between lower prevalence of depression and health behaviors historically only considered preventive for physical illness.

1. Introduction

The burden of chronic illness on individuals and on society is well-documented (Centers for Disease Control and Prevention. Health and Economic Costs of Chronic Disease. Published, 2019). The Centers for Disease Control and Prevention has stated that the majority of chronic illness can be traced back to only a few high-risk behaviors: poor diet, inactivity, and tobacco and alcohol use (Centers for Disease Control and Prevention. How You Can Prevent Chronic Diseases. Published, 2019). A growing body of research examines how these healthy behaviors may beget each other (Fleig et al., 2014, 2015; Nair et al., 2015; Priebe et al., 2017). A prime example of this relationship is illustrated in research showing that a full night of sleep is both directly beneficial for chronic disease prevention and also increases the likelihood of engaging in other health-promoting behaviors such as exercise, maintenance of a healthy diet, and emotional regulation (Atkinson and Davenne, 2007; Dashti et al., 2015; Goldstein and Walker, 2014; Greer et al., 2013). While longitudinal and intervention studies have found that physical activity has a direct positive impact on mental health outcomes, there is also evidence that physical activity may promote prosocial behavior and relatedness, which in turn have direct impacts on long-term health (World Health Organization, 2020; Harold et al., 2013). Likewise, recent studies have determined that loneliness is as impactful on early mortality as smoking is, and one of the pathways to explain this may be that diet quality and physical activity levels can suffer as a result of social isolation (Holt-Lunstad et al., 2015; Conklin et al., 2014; Whitelock and Ensaff, 2018; Chen et al., 2018).

Recent research on "multiple health behavior change" (MHBC[2]) explores the efficacy of changing several high-risk behaviors simultaneously in order to achieve improved habit-formation and health impact (Amireault et al., 2018). While it is clear from numerous studies that engaging in more healthy behaviors rather than less confers greater risk reduction for many chronic illnesses, the question has not been answered whether the effect of multiple healthy behaviors together is

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[1] CHIS: California Health Interview Survey.
[2] MHBC: multiple health behavior change

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greater than the sum of the effects alone (Kvaavik et al., 2010; Lv et al., 2017; Ford et al., 2009; Aleksandrova et al., 2014). To the best of our knowledge, a study has yet to examine MHBC under the hypothesis that interaction between healthy behaviors could provide additional benefit for well-being, beyond the impact of the healthy behaviors acting individually.

We explore the association between multiple healthy behaviors combined and odds of experiencing one of two of the more common chronic conditions: type II diabetes, via a glucose regulation impairment proxy, and depression. While researchers have explored similar questions in respect to cancer, heart disease, and diabetes, this is the first study we are aware of to explore the relationship of a mental illness outcome variable with the same healthy behaviors generally included in MHBC research (Kvaavik et al., 2010; Lv et al., 2017; Aleksandrova et al., 2014; Investigation, 2009). Primary prevention of mental illness is less studied than methods of early intervention, crisis stabilization, or other evidence-based interventions applicable in cases of more severe mental illness. We seek to add to the conversation on critical and effective, low-barrier, daily-use methods for maintaining mental well-being that are available at the public health scale.

We use an evidence-based list representing the core set of health behaviors that are broadly agreed upon by public health experts and are included in previous MHBC studies, as available in the data source: healthy dietary factors, physical activity, avoidance of tobacco use, community engagement, and water consumption (Kvaavik et al., 2010; Lv et al., 2017; Aleksandrova et al., 2014; Investigation, 2009). We hypothesize that the core list of primary prevention health behaviors for maintenance of mental well-being generally mirrors that for physical well-being, as indicated in a growing body of research exploring the etiology of mental illness (Atkinson and Davenne, 2007; Dashti et al., 2015; Goldstein and Walker, 2014; Greer et al., 2013; World Health Organization, 2020; Harold et al., 2013; Holt-Lunstad et al., 2015; Conklin et al., 2014; Whitelock and Ensaff, 2018; Chen et al., 2018). (Note: The variables available for inclusion in this study are naturally limited by those in the data source. The CHIS 2017 survey did not include questions on alcohol consumption or sleep quantity/quality.)

It is worth noting the possibility of co-occurrence of impaired glucose regulation and depression. Evidence indicates that the co-occurrence of these two conditions leads to worse health outcomes and higher health care costs (Alva and Ikeda, 2020). In addition, these conditions may share underlying biological and behavioral causes, thus increasing the value of determining healthy behaviors that positively impact both (Holt et al., 2014).

We hypothesize that the odds of having impaired glucose regulation, and of having depression, are lower with each additional healthy behavior exhibited and that the magnitude of the change in odds is greater with each subsequent additional healthy behavior.

The implications of these findings are pertinent to health promotion and health education professionals, to individuals who experience mental illness and the professionals that support them, as well as those that work in health systems and policy.

2. Methods

2.1. Study design and population

The present study examines the adult population from the 2017 California Health Interview Survey (CHIS) (University of California Canter for Health Policy Research, 2018). CHIS is the largest state health survey in the United States, asking questions on a wide-range of health topics via telephone response (Survey and Design, 2019). The survey is conducted across California on a rolling basis each year (Survey and Design, 2019). The approval and methodology for this survey of is explained in detail in CHIS resources (Survey and Design, 2019). Approval for the present study was granted by the California Committee for the Protection of Human Subjects. A total of 21,153 adults contributed to the 2017 survey, with a total of 21,116 adults included in the present analysis due to missing data on diabetes and/or depression diagnosis for 37 individuals.

2.2. Type II diabetes and depression ascertainment

For the purposes of this study, the type II diabetes outcome is broadly defined using a proxy of impaired glucose regulation: by "yes" responses to any question determining if a doctor had ever given the respondent a diagnosis of type II diabetes, double diabetes, or prediabetes (does not include gestational diabetes). The depression outcome was defined using a score of 13 or above on the validated Kessler-6 scale, which screens for general psychological distress, and also measures severity. Respondents are asked how often in the past 30 days have they felt: nervous; hopeless; restless or fidgety; worthless; "so depressed that nothing could cheer you up"; "that everything was an effort". Answers *All, Most, Some, A little*, and *None of the time* are scored 4 to 0 points, respectively. A cumulative score of 13 and above is widely used to categorize "serious mental illness." (Prochaska et al., 2012) While the Kessler-6 scale is not a clinical depression diagnosis tool, investigations of the ability of this scale to predict diagnosis (including depression) based on the Diagnostic and Statistical Manual of Mental Disorder and known correlates of mental illness severity substantiate its use for proxy measures, such as it is used here for depression (Mitchell and Beals, 2011).

2.3. Healthy behavior ascertainment

The list of healthy behaviors was determined based on *apriori* knowledge of chronic disease prevention and on extensive literature review, and represent a core set of healthy behaviors used across MHBC and primary prevention research. The determination of the point at which to dichotomize each variable into "healthy" and "unhealthy" behavior was based on bodies of research demonstrating the relationship between the lifestyle factor and chronic disease, including national public health recommendations. We build upon the body of research that uses this large dataset, however that comes with natural limitations in the variables used within this study.

2.3.1. Dietary factors

This is a composite variable formed from weekly soda consumption and daily fruit and vegetable intake. Average monthly fruit intake and vegetable intake were used to calculate an average combined fruit and vegetable intake per day. Respondents who consumed an average of less than four sodas per week *or* consumed five or more fruits and vegetables per day were considered to have "healthy" dietary factors (U.S. 2015; Malik et al., 2010).

2.3.2. Exercise

While extensive research shows a dose–response relationship between exercise and disease, the World Health Organization now recommends getting 150-mintues per week of moderate moderate-intensity aerobic physical activity to prevent chronic illness (World Health Organization. Physical Activity Fact Sheet, 2020). Thus, exercise was dichotomized as "healthy" if the respondent had exercised five or more times in the past seven days (an average of 30 min of per event is thus assumed, to meet the recommended weekly minimum of 150 min).

2.3.3. Smoking

This variable is dichotomized based on whether respondent has smoked 100 or more cigarettes in their lifetime.

2.3.4. In-person community engagement

This variable was also composed of multiple variables related to in-person engagement, as available in the CHIS dataset. "Healthy" community engagement was determined if respondents answered "Agree" or

"Strongly Agree" to one or more of the following statements: people in the neighborhood are willing to help each other, people in the neighborhood get along, people in the neighborhood can be trusted; *and* the respondent must have also stated that they had completed volunteer work in the community in the past year. This variable is built on a growing body of research showing that social isolation is as strong a predictor of early mortality as tobacco use (Holt-Lunstad et al., 2015).

2.3.5. Water consumption

Consumption of sugar-sweetened beverages or other calorie-positive beverages is very common in lieu of water consumption, which is necessary for normal body functioning, thereby dramatically altering energy balance (Panel on Dietary Reference Intakes for Electrolytes and Water and Committee, 2005; Dubois et al., 2007; Dennis et al., 2010; Jahns, 2019). A specific recommendation on water intake is not given by the USDA due to the variability based on body size, water content in the diet, activity level and environmental factors (Panel on Dietary Reference Intakes for Electrolytes and Water and Committee, 2005; Jahns, 2019). Thus, we calculated an average amongst the total study population of the number of "times in the previous day" that water was consumed, and a healthy level of water consumption was determined as greater than this population average. No other measure of water quantity nor adequacy per individual was captured in the survey data.

2.4. Covariates

It is well established that healthy behaviors often cluster together as a result of age, gender, education level, income, and access to other health-promoting determinants (Marmot, 2005; World Health Organization, 2017). These determinants in turn impact glucose regulation and depression outcomes. Thus, we included age, gender, physical disability status, and percent of federal poverty level as confounders in all adjusted models. The prevalence of people who are physically disabled in the extent that they cannot walk is small for all groupings but is important for both exercise ability and for disease outcomes. We present descriptive analyses by race category as well, while echoing calls for improved methodology for conceptualizing socioeconomic variables (Bowleg, 2019). All covariates were confirmed for confounding relationship in chi-square tests ($p < 0.05$).

2.5. Healthy lifestyle index (HLI) definition

Each healthy lifestyle factor was dichotomized to allow for easy translation of research findings, alignment with current health guidelines, and to allow for construction into an index variable. Study participants were given a point for each of the aforementioned five healthy lifestyle factors exhibited in their responses, with a point range of 0 to 5. Thus, the HLI variable was a sum of all "healthy" behavior points, per respondent, with 0 representing least healthy and 5 representing most healthy behaviors.

2.6. Statistical analyses

In descriptive analyses we present prevalence of each healthy behavior, each level of the HLI, and each disease outcome, for the full cohort and among women and men, and among seven race categories. We also present averages and standard deviations for the full cohort and by disease outcome for age and percent of federal poverty level. We present odds ratios with 95% confidence intervals (CI's) for each disease outcome modelled against each binary predictor alone, each binary predictor adjusted for confounders, all binary predictors in a crude model, and all binary predictors while adjusting for all confounders. These results are shown in Tables 2(a) and (b).

For the primary analysis, we present a full multivariable logistic regression model including the binary predictors as the combined HLI for odds of impaired glucose regulation (shown as "diabetes" in tables) and of depression, with and without adjustment by the aforementioned covariates. Participants with all five healthy factors are the reference group. HLI was modeled as a categorical variable, under the assumption from which the hypothesis is based – that the relationship between HLI and odds of impaired glucose regulation/depression is not linear. Additionally, we executed contrast analyses to allow for comparison between each two sequential levels of the HLI. We also present HLI modelled ordinally, for comparison.

All statistical analyses were performed using the Statistical Analysis System (SAS) Version 9.4; SAS Institute, Inc., Cary, NC, USA. P-values were based on two-sided tests, and $p < 0.05$ was considered statistically significant.

2.7. Theory

The use of a combined HLI is the most common method for examining multiple health behavior change impact on disease (Kvaavik et al., 2010; Aleksandrova et al., 2014; Investigation, 2009). While the method we used in this study is the most common in the field of MHBC research, we urge other studies upon this or similar research questions to consider using a model with interaction terms instead. There is no evidence for use of this method in such application at the time of completion of this analysis.

3. Results

3.1. Descriptive analyses

Of the total 21,116 adult study population, the mean age was 46 (±0.19) years, and the cohort was 51% women. Overall, 19.3% were classified as having impaired glucose regulation, and 10% with depression. The prevalence of impaired glucose regulation varied slightly across genders, with 18% of women and 20% of men classified as diabetic, while 11% of women and 8% of men were classified as having depression. The mean for the study population of percent of federal poverty level was 450% (±4%) (equivalent to approximately $54,630 annual salary for one person in 2018 US Dollars, $112,950 for a family of four), and that average drops in both the disease categories: 413% (±9%) and 355% (±13%) for impaired glucose regulation and depression, respectively (Office of the Assistant Secretary for Planning and Evaluation., 2018). The prevalence of each disease varies between race categories: for both impaired glucose regulation and depression, those who identified as White report the lowest prevalence, while impaired glucose regulation prevalence is highest for those who identified as African American, and Hawaiian Island/Pacific Islanders report the highest depression prevalence. Percent of study participants who engage in 0, 1, 2, 3, 4, and 5 healthy lifestyle behaviors follows a symmetrical modal distribution. Further details, as well as percent of the cohort and of each race reporting each healthy lifestyle factor and each HLI level are provided in Table 1.

3.2. Primary findings

3.2.1. Depression

Every sequential reduction in healthy lifestyle index level from the reference group (HLI = 5 healthy behaviors) was associated with an increased odds of depression, after adjusting for covariates. Compared with participants at the HLI level of 5, the adjusted odds ratio for participants with HLI of 4 was 1.04 (0.72–1.51), 1.14 (0.80–1.62) for 3 factors, 1.48 (1.03–2.12) for 2 factors, 2.16 (1.45–3.22) for 1 factor, and 3.38 (1.89–6.02) for those who reported 0 healthy behaviors. The ratios between 0, 1, 2 compared to 5 were significant at $p < 0.05$. When evaluated as an ordinal variable, each additional level of the HLI was associated with a 20% lower odds of depression (OR for a one-point increase on the HLI = 0.80, CI: 0.74–0.86). When each level of the HLI is compared, instead, against the next consecutive level (rather than

Table 1
Descriptive analyses.

	Total	Diabetes		Depression	
		Yes (%)	No (%)	Yes (%)	No (%)
Participants	21,116	4,715 (19)	17,032 (81)	1,798 (10)	19,014 (90)
Socio-demographic characteristics					
Age (Mean, Standard Deviation)	46 (0.19)	58 (0.41)	44 (0.21)	37 (0.53)	48 (0.20)
Women (%)	51	18	82	11	89
Men (%)	49	20	80	8	92
Percent of Federal Poverty Level (Mean, Standard Deviation)	450 (4)	413 (9)	459 (5)	355 (13)	460 (5)
Race (%)	–	–	–	–	–
Hispanic	36	20	80	11	89
White	41	17	83	9	91
African American	6	29	71	9	91
American Indian/ Alaskan Native	0.4	23	77	12	88
Asian	14	18	82	7	93
Hawaiian/Pacific Islander	0.4	18	82	13	87
Two or more races	2	20	80	21	80
Cannot walk % (Total)	0.4 (184)	–	–	–	–

compared to 5 healthy factors), the odds ratios are: 1.56 (0.93–2.62) for 0 healthy behaviors versus 1, 1.47 (1.13–1.91) for 1 versus 2, 1.30 (1.05–1.60) for 2 versus 3, 1.09 (0.87–1.37) for 3 versus 4, and 1.04 (0.72–1.51) for 4 vs 5. Table 4 and Fig. 1 show that the magnitude of the odds ratios for depression decreases approximately exponentially with each additional healthy lifestyle behavior. In other words, there is less change in chance of depression as each additional healthy behavior is added. Odds ratios, 95% CI's, beta coefficients and p-values for full models are presented in Table 3.

3.2.2. *Type II Diabetes/Impaired glucose regulation*

When compared to the group who reported 5 healthy behaviors and adjusted for covariates, all ratios between fewer healthy behaviors and 5 are statistically significant, except comparing 0 to 5. Compared with participants at the HLI level of 5, the adjusted odds ratio for participants

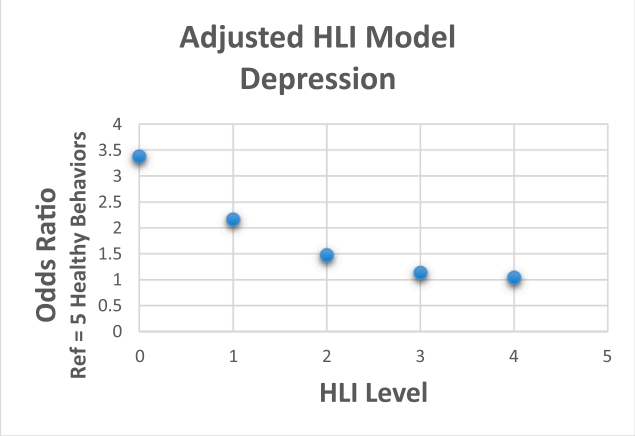

Fig. 1. Odds ratio diagram – Depression.

Table 2
Precursor models.

(a) Single Variable Predictor Models.

Odds of Disease Diagnosis		Single Predictor Variable Models							
	Variable	Crude				Adjusted			
	Ref = Healthy Behavior (0)	OR	95% CI	Beta	p-Value	OR	95% CI	Beta	p-Value
Depression	**Eating**	1.71	1.40–2.10	0.27	<0.0001	1.55	1.25–1.92	0.22	<0.0001
	Exercise	1.12	0.95–1.31	0.05	0.04	1.09	0.93–1.29	0.04	0.29
	Smoking	1.66	1.42–1.93	0.25	<0.0001	2.66	2.22–3.12	0.48	<0.0001
	Comm. Eng.	1.01	0.86–1.17	0.003	0.95	0.99	0.84–1.17	−0.004	0.92
	Water Drinking	0.90	0.77–1.05	−0.05	0.17	0.98	0.84–1.15	−0.01	0.82
Diabetes	**Eating**	0.71	0.57–0.87	−0.17	0.001	0.78	0.63–0.97	−0.13	0.02
	Exercise	1.27	1.12–1.43	0.12	0.0001	1.26	1.11–1.43	0.11	0.0004
	Smoking	1.51	1.35–1.70	0.21	<0.0001	1.07	0.95–1.22	0.03	0.28
	Comm. Eng.	1.28	1.14–1.44	0.12	<0.0001	1.11	0.98–1.25	0.05	0.11
	Water Drinking	1.00	0.90–1.12	0.001	0.97	0.79	0.70–0.89	−0.12	0.0001

(b) Multivariable Predictor Models

Odds of Disease Diagnosis		Multivariable models							
	Variable	Crude				Adjusted			
	Ref = Healthy Behavior (0)	OR	95% CI	Beta	p-Value	OR	95% CI	Beta	p-Value
Depression	**Eating**	1.66	1.36–2.04	0.25	<0.0001	1.42	1.14–1.77	0.18	0.002
	Exercise	1.13	0.96–1.33	0.06	0.13	1.12	0.95–1.33	0.06	0.17
	Smoking	1.62	1.39–1.89	0.24	<0.0001	2.59	2.18–3.07	0.48	<0.0001
	Comm. Eng.	0.95	0.81–1.12	−0.02	0.54	0.97	0.82–1.14	−0.02	0.69
	Water Drinking	0.86	0.74–1.01	−0.07	0.07	0.98	0.83–1.15	−0.01	0.76
Diabetes	**Eating**	0.65	0.52–0.79	−0.22	<0.0001	0.78	0.63–0.97	−0.12	0.02
	Exercise	1.27	1.13–1.44	0.12	<0.0001	1.29	1.13–1.46	0.13	0.0001
	Smoking	1.53	1.37–1.72	0.21	<0.0001	1.08	0.95–1.23	0.04	0.23
	Comm. Eng.	1.29	1.15–1.45	0.13	<0.0001	1.12	0.99–1.27	0.06	0.07
	Water Drinking	0.98	0.87–1.10	−0.01	0.67	0.77	0.68–0.88	−0.13	<0.0001

Table 3
Unadjusted, adjusted, and contrast HLI models.

(a) Unadjusted HLI model

	Healthy Lifestyle Index (HLI) Models				
	HLI Level	Crude			
	Ref = 5 Healthy Behaviors	OR	95% CI	Beta	p-Value
Depression	0 vs 5	2.41	1.38–4.20	0.64	0.00
	1 vs 5	1.52	1.05–2.21	0.18	0.07
	2 vs 5	1.2	0.84–1.70	−0.06	0.47
	3 vs 5	1.02	0.72–1.44	−0.22	0.01
	4 vs 5	0.94	0.65–1.34	−0.31	0.001
Diabetes	0 vs 5	1.69	1–2.85	−0.03	0.89
	1 vs 5	2.44	1.84–3.25	0.34	<0.0001
	2 vs 5	2.07	1.60–2.68	0.18	0.01
	3 vs 5	1.86	1.44–2.39	0.07	0.30
	4 vs 5	1.71	1.31–2.23	−0.01	0.85

(b) Adjusted Model

	Healthy Lifestyle Index (HLI) Models				
	HLI Level	Adjusted			
	Ref = 5 Healthy Behaviors	OR	95% CI	Beta	p-Value
Depression	0 vs 5	*3.38	1.89–6.02	1.22	<0.0001
	1 vs 5	*2.16	1.45–3.22	0.77	0.0001
	2 vs 5	*1.48	1.03–2.12	0.39	0.03
	3 vs 5	1.14	0.80–1.62	0.13	0.48
	4 vs 5	1.04	0.72–1.51	0.04	0.83
Diabetes	0 vs 5	1.01	0.57–1.79	0.01	0.97
	1 vs 5	*1.39	1.03–1.86	0.33	0.03
	2 vs 5	*1.39	1.70–1.82	0.33	0.01
	3 vs 5	*1.41	1.09–1.83	0.34	0.01
	4 vs 5	*1.47	1.12–1.93	0.39	0.01

(c) Contrast Model

	Healthy Lifestyle Index (HLI) Models				
	HLI Level	Contrast			
	Ref = 5 Healthy Behaviors	OR	95% CI	Beta	p-Value
Depression	0 vs 5	1.56	0.931–2.619	0.45	0.09
	1 vs 5	*1.47	1.125–1.910	0.38	0.001
	2 vs 5	*1.30	1.053–1.600	0.26	0.01
	3 vs 5	1.09	0.870–1.370	0.09	0.45
	4 vs 5	1.04	0.720–1.505	0.04	0.83
Diabetes	0 vs 5	0.73	0.425–1.256	−0.31	0.26
	1 vs 5	0.99	0.814–1.213	−0.01	0.95
	2 vs 5	0.99	0.846–1.155	−0.01	0.89
	3 vs 5	0.96	0.809–1.136	−0.04	0.62
	4 vs 5	*1.47	1.122–1.927	0.39	0.01

Table 4
Ordinal model.

Adjusted ordinal model Ref = 5 Healthy Behaviors	OR	95% CI	Beta	p-Value
Depression	1.25	1.16–1.34	0.22	<0.0001
Diabetes	1.01	0.96–1.06	0.01	0.79

with HLI of 4 was 1.47 (1.12–1.93), 1.41 (1.09–1.83) for 3 factors, 1.39 (1.06–1.82) for 2 factors, 1.39 (1.03–1.89) for 1 factor, and 1.01 (0.57–1.79), for those who reported 0 healthy behaviors. Evaluated ordinally, each additional level of the HLI was associated with a 0.7% decrease in odds of impaired glucose regulation (OR for a one-point increase in HLI = 0.993, CI: 0.94–1.04). While the contrast model shows increasingly larger beta coefficients at each subsequent level of comparison—in line with the hypothesis—only the contrast between 4 and 5 is statistically significant.

4. Discussion

In this study, we used a sample of 20,000 + adults living in California to examine the combined associations of healthy dietary factors, adequate physical activity, avoidance of tobacco use, in-person community engagement, and/or water consumption with odds of having a diagnosis of impaired glucose regulation, and separately, of having evidence for depression. Our findings are consistent with previous studies that have found that greater engagement in healthy behaviors is associated with lower prevalence of chronic illness. Longitudinal studies have shown that engaging in 4 healthy behaviors, compared to 0 or 1, can significantly increase life expectancy and decrease cause-specific and all-cause mortality (Ford et al., 2009).

The findings of our study, which solely present association via odds ratio, are also consistent with temporal studies that have found an apparent diminishing of returns in risk reduction associated with each additional healthy behavior. Contrary to our hypothesis, the magnitude of the change in odds of chronic disease decreases with each additional healthy behavior. (The odds of impaired glucose regulation associated with each additional healthy behavior do follow a trend similar to the hypothesized association, however, only the contrast model comparison between 4 and 5 healthy behaviors is statistically significant). Our results for depression mirror those in similar studies in that the odds ratios comparing 0 through 4 healthy behaviors to 5 healthy behaviors decrease approximately exponentially. In fact, some studies have observed that particular combinations of 2 healthy behaviors presented similar reductions in risk to a combination of all 4 healthy behaviors (Ford et al., 2009). One study, however, found that the combination of physical activity and healthy diet yielded a hazard ratio smaller than the expected hazard ratio based on the individual factors alone (Ford et al., 2009). This finding also supports the health promotion idea that achieving a single positive health behavior change is the most difficult but potentially the most rewarding for long-term health. While the finding that a few simple healthy actions can have measurable impact is good news for health education efforts, it runs contrary to our hypothesis that interactions between healthy behaviors themselves could have far greater impacts on odds for chronic disease. Still, it is clear that more combined healthy factors are associated with the smallest odds/risk/hazard ratios for chronic illness, throughout the literature (Aleksandrova et al., 2014; Kvaavik et al., 2010; Ford et al., 2009; Gopinath et al., 2010; Babey et al., 2016).

By exploring the relationship between well-established healthy behaviors and mental well-being, our results augment the fields of MHBC and primary prevention. Our results indicate that healthy behaviors historically only associated with lower prevalence of physical illness are also associated with lower prevalence of mental illness. These findings are important in a time of rising mental illness prevalence and increased need for upstream, primary prevention measures, as well as effective treatment for mild cases of mental illness. In addition, due to the high rate of co-occurrence of mental and physical illness, these results should inspire further exploration of multiple health behavior change in the context of addressing these two spheres of wellness simultaneously.

5. Limitations

Our results should be taken in the context of the limitations presented. Most notably, the cross-sectional nature of the data introduces significant difficulty in understanding the temporality of the independent and dependent endpoints tested here, and makes determinations of causation impossible. This issue is clear in the descriptive results that exhibit poor dietary factors and low water consumption are associated with a *decreased* odds of impaired glucose regulation diagnosis, contrary to hypotheses and public health recommendations. The fact that these

associations are also not observed in the odds for depression may indicate that a past glucose regulation impairment diagnosis prompted recent changes in diet or altered reporting on diet, while this temporality is not captured in the survey design. The outcome variables are likely under-reported by this data source. Prediabetes and depression are chronically underdiagnosed, and persistent stigma around mental illness increases the likelihood for under-reporting (Corrigan, 2004; Sartorius, 2007). Finally, though it is not common practice in similar MHBC studies, there is evidence to support applying weights to each behavior. Diet, exercise, and tobacco use have been proven to have very strong relationships with chronic disease prevention. However, there is also growing evidence that both objective and subjective loneliness are as impactful on mortality as tobacco use, and while not included in this study due to the exclusion from the original data source, sleep has profound impacts on health behaviors and risk for chronic illness. Thus, we posit that as more research explores the impacts of these as-yet underestimated health behaviors both on chronic disease and on each other, their importance may become clearer.

5.1. Strengths

To the best of our knowledge, this is the first study that has explored the associations of interactions *between* healthy behaviors and their subsequent impact on chronic illness. We used a method well-established in the literature base and parsimoniously used variables from an existing data set to examine health behaviors with strong evidence base in chronic disease prevention. The use of CHIS data enables statistically relevant results and increased generalizability due to the large and diverse sample population and the survey's robust design, implementation, and data processing.

MHBC research has historically sought to examine the potential psychological benefits of changing multiple health habits simultaneously, as opposed to one habit at a time. In focusing on MHBC, we use a framework proven to contribute to primary prevention and health improvement. Our study expands the investigation to an exploration of how healthy behaviors *beget each other*, and the overall impact on chronic illness. Furthermore, the results of this study add a new perspective to the field of MHBC and to health promotion, in the expansion of understanding the association of health behaviors and mental wellness. In addition, this study is the first we can find to investigate the association of MHBC on mental illness.

6. Conclusion

As mental illness incidence increases across the United States, primary prevention measures and easily-applicable treatment for mild cases are increasingly important. Our results also suggest that engaging in even one healthy behavior may dramatically decrease the odds for having depression, regardless of the type of healthy behavior chosen. This can be a powerful message for health promoters and educators because the impacts of healthy behavior upon mental well-being can be immediate. Our study also highlights the need for further investigation of the psychological and physiological pathways along which healthy behaviors beget other healthy behaviors. Further investigation of the interaction *between* healthy behaviors, and their combined impact on chronic disease prevention, should be strengthened with longitudinal and randomized control studies, and exploration of this question using a model with interaction terms.

7. Disclosure of funding source

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8. Research Data

Due to the sensitive nature of the questions asked in the California Health Interview Survey, which was used for this study, survey respondents were assured raw data would remain confidential and would not be shared.

CRediT authorship contribution statement

Madison Sheffield: Conceptualization, Methodology, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Carol Lewis:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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